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UNMANNED AERIAL RECONNAISSANCE VEHICLE (UARV) IMAGERY INTERPRETATION STUDY

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13. ABSTRACT (Maximum 200 words)
This study was conducted because the end product of reconnaissance is the intelligence report generated by the interpreter without imagery usable by an interpreter. The entire UARV system would be useless. A unique approach was utilized in developing technology requirements for UARVs by first identifying what was required for image interpretation and then propagating these requirements up to the vehicle subsystems level.

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An IMA is a ready reserve member assigned to a regular Air Force unit to support the unit's mission immediately following a declaration of war or national emergency or to respond to any situation that national security requires. IMAs participate in the execution of the unit's mission and often perform active duty assignments when the unit requires additional support on specific tasks. The primary purpose is to maintain a high level of readiness for the IMA and to fulfill mission needs.

At Rome Laboratory, IMAs work side by side with active duty forces to direct and perform the research of the Laboratory. The Laboratory calls upon the IMAs to provide specific expertise (often related to the IMA's civilian occupation) and to meet surge requirements.

This report is a product of Rome Laboratory's IMAs assigned to the Image Systems Division of the Intelligence and Reconnaissance Directorate.

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We would like to thank Mr Gerald C. Nethercott, Chief of the Image Exploitation Branch of the Rome Laboratory, for his guidance and encouragement. Mr Ronald B. Haynes and MSgt Charles R. Walling of the Image Exploitation Branch provided the active day to day interaction with most of the participants.

Specific acknowledgements are to be given to Ms Kathy A. R. Jones of Boeing Military Aircraft Corporation and Mr Max Rodgers at Knowledge Systems Concepts, Incorporated, who directed the contractor support and gathered the basic data used to generate this final product. We would also like to gratefully acknowledge all others who provided the information so freely. The complete list of contributors is too long to be included here, and is contained in Appendix D.

EXECUTIVE SUMMARY

This report documents the results of the "Unmanned Aerial Reconnaissance Vehicle (UARV) Imagery Interpretation Study". The study determined areas of technology advancement the Government and Industry must pursue to support the UARV program. The basis for these technology drives, and hence the recommendations of this report, is the difference between an image interpreter's image quality needs and current UARV payload capabilities.

We conducted the study in four phases. The first phase reviewed image interpreter requirements in terms of image quality needed to perform the specific tasks described by requirements documents. In phase II, we reviewed UARV subsystems to determine which were critical to the reconnaissance mission. Phase III analyzed the systems issues and imagery requirements to determine where technology met the requirements and where there were shortfalls. Phase IV identified technology research and development activities needed to cover the shortfalls. The study phases were performed under contract to the Rome Laboratory (RL/IRRE) by Knowledge Systems Concepts, Inc and Boeing Military Aircraft Corporation. Air Force Reserve personnel assigned to Rome Lab used material generated under the contract to assemble this report.

The study focused on the Short Range UARV since requirements for this vehicle are fairly well defined and can be compared to available technology. This allowed us to develop and review the study methodology based on realistic data. The study was not intended to be an in-depth analysis, but rather, to develop a methodology that can be used as a model for future analytical processes relating to reconnaissance vehicles, including the other classes of UAVs. The results were presented to the UAV Joint Program Office (JPO), and were warmly received.

These results show that area search missions and route reconnaissance missions required for the Short Range UARV can be performed with sensors with nominal resolutions of 3-5 feet, and still satisfy the imagery interpreter's resolution requirements. For point targets, sensors capable of resolutions of 4-16

inches are required to satisfy all of the essential elements of information (EEI's). The estimated weight of these high resolution payloads potentially exceeds the payload weight capacity envisioned for the Short Range UARV. Therefore, the main emphasis of technology should be to reduce system/payload weight while increasing equipment performance to achieve the high resolution capability.

In addition to reducing component weights via miniaturization, we recommend development of an interoperable data link with the data rate necessary (28 Mb/s) for high resolution imaging; a more compact MIL-STD-2179 data recorder based on the 8 mm tape and tailored to the data rates and volumes of the UARV mission; and a lightweight digital navigation/flight control system with Global Positioning System (GPS) accuracy. Specific recommendations are detailed in section 4.

1.0 INTRODUCTION

This report documents the results of the "Unmanned Aerial Reconnaissance Vehicle (UARV) Imagery Interpretation (UARVII)" study. We conducted the study because the end product of the imagery reconnaissance is the intelligence report generated by the image interpreter. Without imagery usable by an interpreter, the entire UARV system would be useless. A unique approach was utilized in developing technology requirements for UARVs by first identifying what was required for image interpretation and then propagating these requirements up to the vehicle subsystems level. Sponsored by Rome Laboratory (RL, previously the Rome Air Development Center, RADC), the study covered most aspects of the Short Range UARV problem. Our primary intent is to demonstrate the methodology and provide useful data on the specific mission in hand.

The reconnaissance community is transitioning from hardcopy (film) exploitation systems towards digital (electronic) softcopy exploitation techniques. Digital collection and exploitation systems offer many advantages over film based systems. In 1986/87, Rome Lab and other government agencies demonstrated that digital systems provide quality imagery within the timeliness required for tactical applications (see RADC report RADC-TR-87-145). Figure 1.0-1 shows the future tactical reconnaissance scenario. Using electro-optical (EO) and infrared (IR) imagery in the near term and SARs and three dimensional laser radars in the future, advanced digital exploitation concepts, and a modular, interoperable common ground station, commanders can count on timely, accurate, imagery-derived intelligence information.

Interoperability is another aspect of reconnaissance that must be considered in our analysis. In the UARV context, interoperability allows exchange of battlefield imagery data between battle elements. Numerous studies have shown that this provides a significant force multiplier and enhances force deployment flexibility. There are a number of current efforts to develop interoperability both within US forces and between those of the NATO members. NATO STANAG 7023 is being developed to define the imagery formats to be used, while NATO STANAG 7024 and MIL-STD-2179 define standard digital recorders. The NATO Interoperable Imagery Data Link Study (NIIDLS) is defining the concepts for data

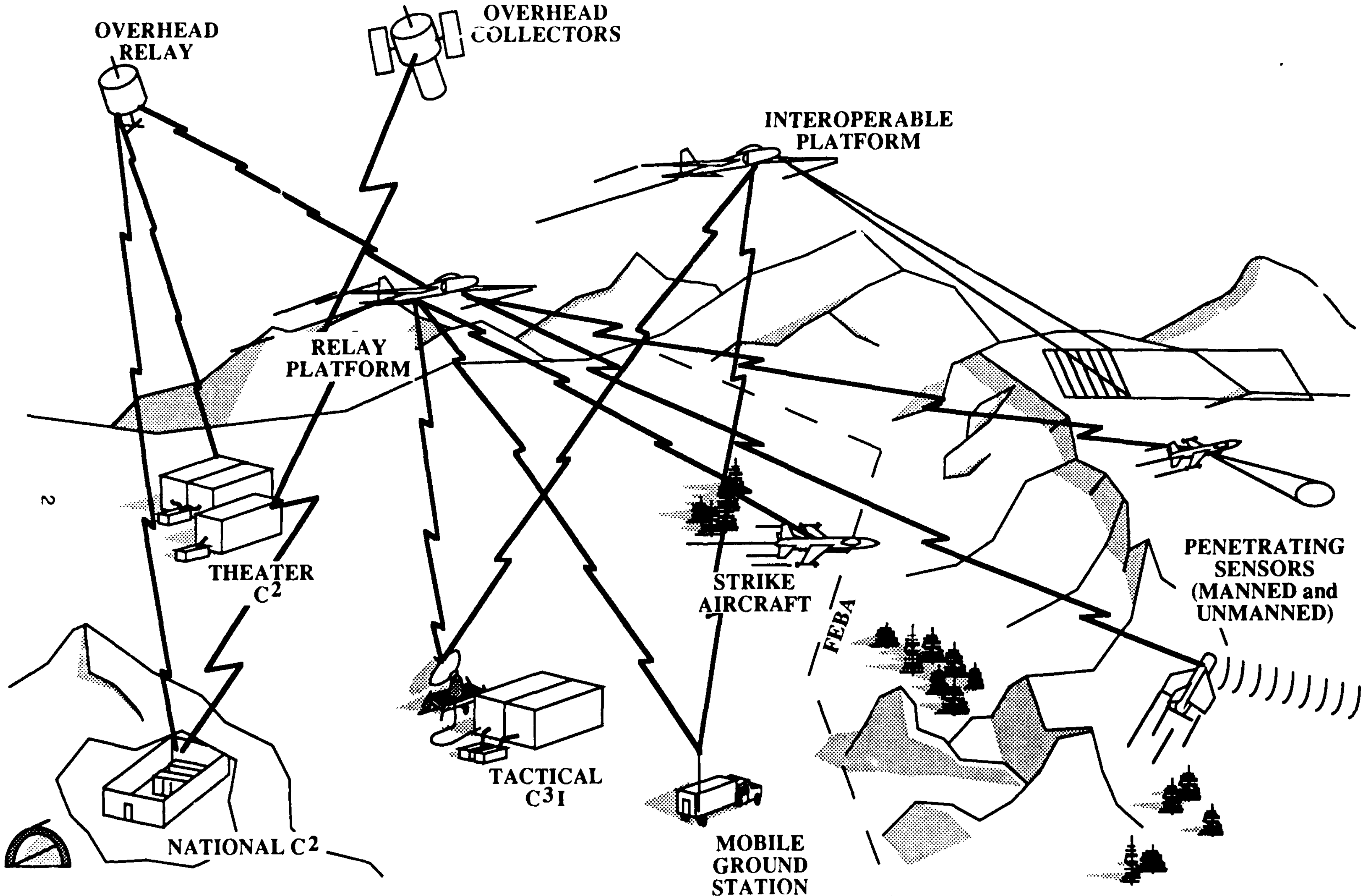


Figure 1.0-1 Future Tactical Reconnaissance Scenario

link interoperability. The Common Data Link (CDL) Program is developing a family of data links which will be used for a variety of applications. The concept of complete interoperability may or may not be practical or mission essential. A current study effort, the UARV NATO Interoperability Design Study (UNIDS), will develop recommendations on the level of interoperability applicable to UARVs.

Figure 1.0-2 depicts the study's methodology. Boeing Military Airplanes (BMA) and Knowledge Systems Concepts (KSC) jointly performed the research under the direction of RL/IRRE. Results of the contractor's efforts were used in conjunction with a government performed mission analysis and review to prepare an interim report entitled "Imagery Interpretation Requirements for Reconnaissance Systems" (RADC-TR-90-370, by MSgt Charles Walling, Rome Laboratory, Griffiss AFB NY, December 1990). Air Force Reserve officers also used this information to compose this final report. The scope of the study was to perform a "quick look", high-level analysis that would validate the methodology as being applicable to all classes of reconnaissance vehicles.

The study team conducted this effort in four phases. In phase I, detailed Army, Navy, and Marine Corps imagery requirements for the Short Range UAV (UAV-SR) system were analyzed. We selected the Short Range UAV because this program is already defined and systems are in development. The imagery requirements analysis showed that a NIIRS (National Imagery Interpretability Rating Scale) 6 quality image was the actual stated need of the services. The NIIRS scale reflects the information content of imagery. Although related to resolution, dynamic range, and other parameters of the image, the scale is technically independent of these variables and is intended to reflect the information in the image. Figure 1.0-3 summarizes the NIIRS scale. These requirements are also reflected in MSgt Walling's interim report for phase I.

Phase II analyzed vital reconnaissance system/support system components (sensors, data links, recorders, navigation accuracy, and control considerations unique to UAVs) within the stringent weight, electrical power, and space constraints of the UARV platform. This analysis, performed independently of the imagery requirements phase, showed that with current technology, an integrated Short Range UARV system is capable of providing only NIIRS 3 imagery. Thus, there exists an image resolution shortfall: image interpreters require NIIRS 6 to adequately perform their job, but present capabilities, consistent with Short Range UARV specifications, allow only for NIIRS 3 collection.

Therefore, Phase III assessed technology research and development approaches that could reduce or eliminate the shortfall between requirements and capability. Risk assessments of the identified Research and Development approaches completed the study as Phase IV.

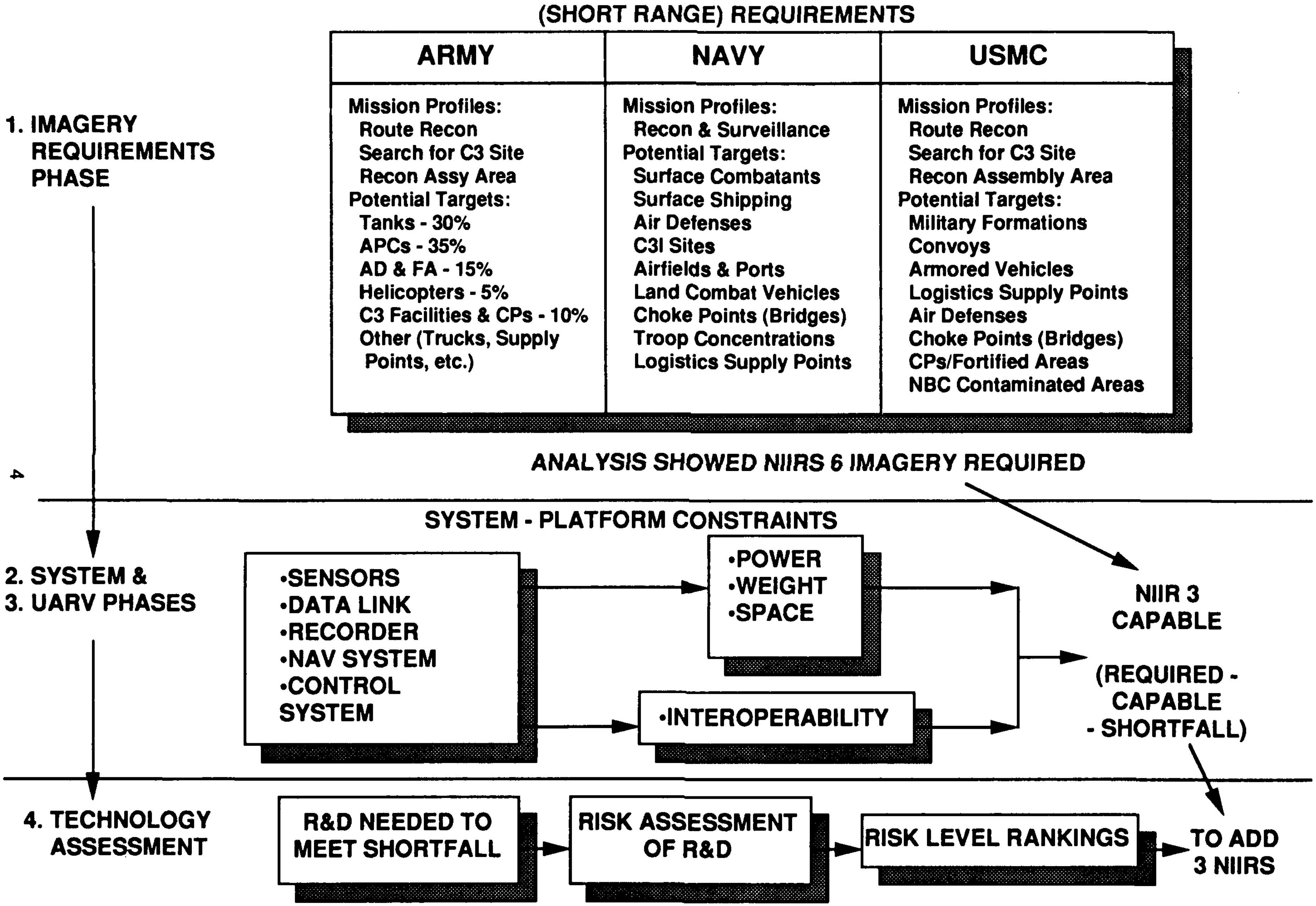


FIGURE 1.0-2 UARV IMAGERY INTERPRETATION STUDY METHODOLOGY

Rating Level 0

- Interpretability of the imagery is precluded by obscuration, degradation, or very poor resolution.

Rating Level 1

- Detect a medium size port facility and/or distinguish between taxiways and runways at a large airfield.

Rating Level 2

- Detect large hangers at airfields.
- Detect large static radars (e.g., AN/FPS-85, COBRA DANE, PECHORA/KRASNOYARSK, HENHOUSE).
- Detect military training areas.
- Identify an SA-5 site based on road pattern and overall site configuration.
- Detect large buildings at a naval facility (e.g., warehouses, construction halls).
- Detect large buildings (e.g. hospitals, factories).

Rating Level 3

- Identify the wing configuration (e.g., straight, swept, delta) of all large aircraft (e.g., 707, Concord, BEAR, BLACKJACK).
- Identify radar and guidance areas at a SAM site by the configuration, mounds, and presence of concrete aprons.
- Detect a helipad by the configuration and markings.
- Detect the presence/absence of support vehicles at a mobile missile base.
- Identify a large surface ship in port by type (e.g., cruiser, auxiliary ship, non-combatant/merchant).
- Detect trains or strings of standard rolling stock on railroad tracks (not individual cars).

Rating Level 4

- Identify all large fighters by type (e.g., FOXBAT, FULCRUM, F-15, F-14).
- Detect the presence of large individual radar antennas (e.g., TALL KING).
- Identify, by general type, tracked vehicles, field artillery, large river crossing equipment, wheeled vehicles, when in groups.
- Detect an open silo door.
- Determine the shape of the bow (pointed or blunt/rounded) on a medium size submarine (e.g., ROMEO, HAN, Type 209).
- Identify individual tracks, rail pairs, control towers, switching points in rail yards.

Rating Level 5

- Distinguish between a MIDAS and CANDID by the presence of refueling equipment (e.g., pedestal and wing pod).
- Identify radar as vehicle mounted or trailer mounted.
- Identify, by type, deployed tactical SAM systems (e.g., FROG, SS-21, SCUD, LANCE).
- Distinguish between SS-20/SS-25 mobile missile TELs and missile support vans (MSVs) in a known support base, when not covered by camouflage.
- Identify TOP STEER or TOP SAIL air surveillance radar on KIROV, SOVREMENNY, KIEV, SLAVA, MOSKVA, KARA, or KRESTA-II class vehicles.
- Identify individual rail cars by type (e.g., cattle, enclosed box) and/or locomotive by type (e.g., steam, diesel).

Rating Level 6

- Distinguish between models of small/medium helicopters (e.g., HELIX A from HELIX B from HELIX C, HIND D from HIND E, HAZE A from HAZE B from HAZE C).
- Identify the shape of antennas on EW/GCI/ACQ radars as parabolic, parabolic with clipped corners, or rectangular.
- Identify the spare tire on a medium sized truck.
- Distinguish between SA-6, SA-11, and SA-17 missile airframes.
- Identify individual hatch covers (8) of vertically launched SA-N-6 on SLAVA class vessels.
- Identify automobiles as sedans or station wagons.

Rating Level 7

- Identify fitments and fairings on a fighter sized aircraft (e.g., FULCRUM, FOXHOUND).
- Identify ports, ladders, vents on electronics vans.
- Detect the mount for anti-tank guided missiles (e.g., SAGGER on BMP-1).
- Distinguish between the inner and outer liner in a missile silo when the door is open.
- Identify the individual tubes of the RBU on KIROV, KARA, KRIVAK class vehicles.
- Identify individual railroad ties.

Rating Level 8

- Identify rivet lines on bomber aircraft.
- Detect horn-shaped and W-shaped antennas mounted atop BLACK TRAP and BLACK NET radars.
- Identify a hand held SAM (e.g., SA-7/14, REDEYE, STINGER).
- Identify joints and welds on a TEL or TELAR.
- Detect winch cables on deck mounted cranes.
- Identify windshield wipers on a vehicle.

Rating Level 9

- Differentiate cross-slot from single slot heads on aircraft skin panel fasteners.
- Identify small light-toned ceramic insulators which connect wires of an antenna canopy.
- Identify vehicle registration numbers (VRN) on trucks.
- Identify screws and bolts on missile components.
- Identify braid of rope (1-3 inches in diameter).
- Detect individual spikes in railroad ties.

Figure 1.0-3
National Imagery Interpretability Rating Scale (NIIRS)

The interim report and an outline of this report were presented to the UAV Joint Program Office (JPO). JPO personnel stated that the study's findings describe clearly where they are today with the Short Range program, and agreed with the study's conclusions and recommendations on where they

would like to be. Moreover, the JPO enthusiastically embraced the methodology of our study for use in other UAV class programs. Even though these results may not be statistically valid, they are supportive of the intuitive opinions of the UAV JPO office as well as other experienced operators, users, and decision makers of the reconnaissance mission arena.

2.0 APPROACH

Figure 2.0-1 illustrates the study's four major phases. In Phase 1, we defined an imagery interpreter's (II's) needs in terms of the resolution required to detect, recognize, identify and classify specific targets. These resolution requirements along with JPO-derived specifications were reviewed to

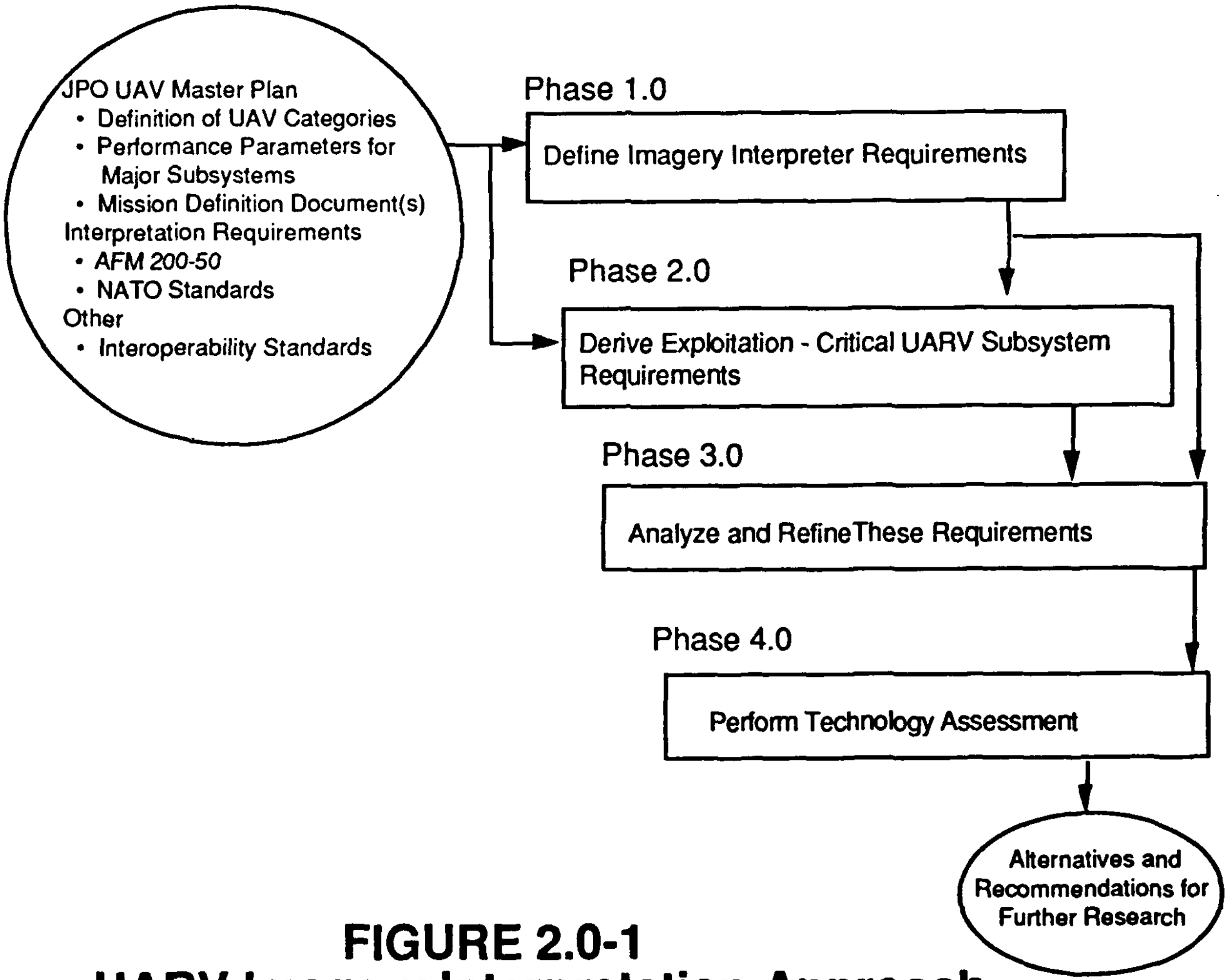


FIGURE 2.0-1
UARV Imagery Interpretation Approach

define the performance drivers for critical vehicle systems/subsystems in Phase 2. The results of Phases 1 and 2 were then analyzed and refined in Phase 3 to produce a final set of vehicle system/subsystem requirements. This final set of vehicle system requirements was used in Phase 4 as a basis to assess how well existing technologies could satisfy the Short Range UAV operational requirements. Out of Phase 4 came recommendations for future technology development. The Joint Program Office UAV Master Plan outlines four types of unmanned air vehicles. We selected the Short Range UAV as the focus of this study because of the existence of available specifications and mission descriptions for this vehicle.

The analysis that follows uses numerous terms which describe the various parameters and characteristics of the reconnaissance environment. If additional information is required, you are referred to Appendix A, Terms of Reference.

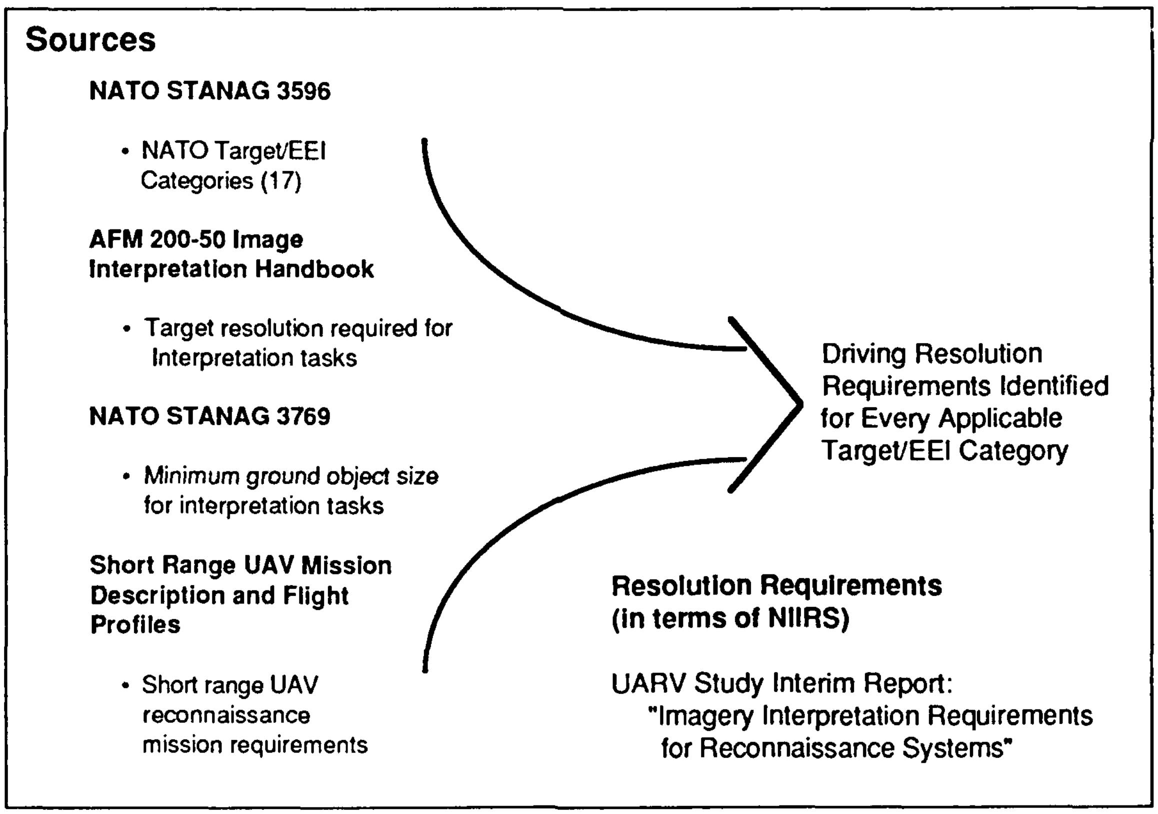


Figure 2.1-1
Resolution Requirements Development

2.1 Phase 1: Imagery Interpretation Requirements

This phase determined imagery interpretation resolution requirements for target categories utilized in Short Range reconnaissance missions based on handbooks and standards used by the operational forces. Figure 2.1-1 shows a simple representation of the development process for this phase. As shown, we integrated various reconnaissance standards and mission documents to arrive at non-ambiguous requirements. Standard reference documents were used to define the tasking to image interpreters in the operational environment. NATO STANAG 3596 - Annex B ("Air Reconnaissance Target and Reporting Guide") provides a list of seventeen target categories along with the specific information elements that must be answered for each category during the tasking process. This document also outlines codes relating to the purpose of each tasking request and provides examples of various tasking requests. The information elements are called "essential elements of information" (EEIs). Three examples of these target/EEI categories are provided in Figures 2.1-2, 2.1-3, and 2.1-4. They are examples of an 'airfield', 'military activity', and a 'shipping' target category with associated EEI's, respectively. (These examples are taken from RADC-TR-90-370.)

NATO STANAG 3769 Annex C("Minimum Resolved Object Sizes for Imaging Interpretation") and Air Force Manual 200-50 ("Image Interpretation Handbook") specify what ground resolved distance (GRD) is required for image interpretation tasks. For instance, both documents contain a ground resolution requirement for aircraft detection ("aircraft" is the target type while "detection" is the interpretation task). Since there are five levels of interpretation tasks outlined in the Air Force manual (detection, general identification, precise identification, description, and analysis), while there are only four NATO interpretation tasks (detection, recognition, identification, and technical analysis); we incorporated both standards together before applying them in the UARV study.

RADC TR-90-370, "Imagery Interpretation Requirements for Reconnaissance Systems" compiles the work performed under phase I. It outlines a method for developing an imagery interpreter's resolution requirements based on current intelligence and tasking standards. Using the Short Range UAV as an example, specific resolution requirements were derived. The report contains further information regarding the resolution requirements development process.

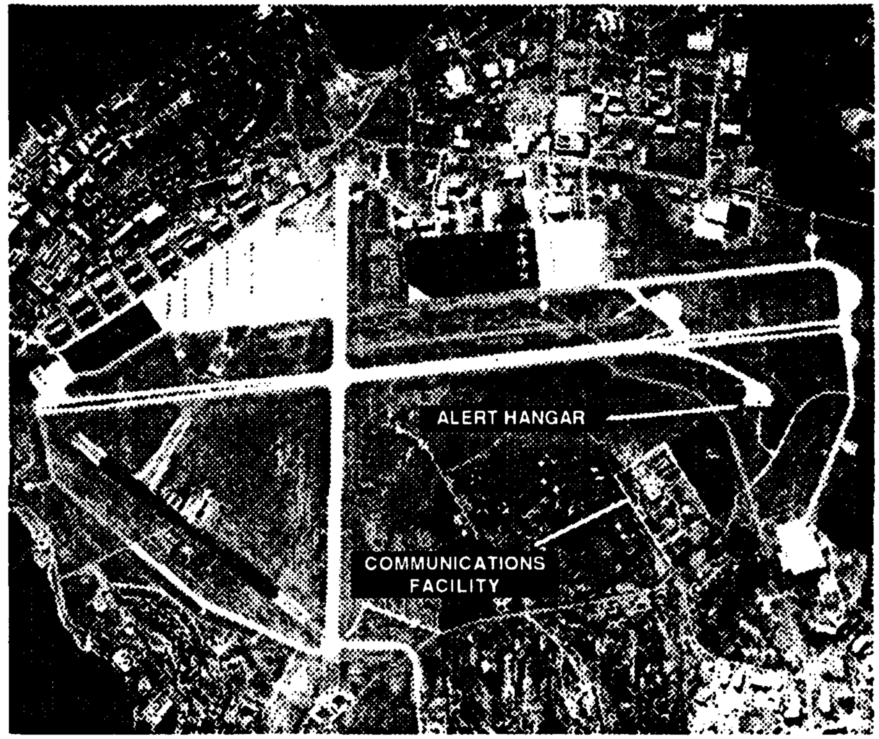
The UAV JPO document, "Short Range UAV Mission and Flight Profiles", outlines Short Range reconnaissance mission descriptions. These descriptions, together with the target/EEI categories and the necessary object resolution, were used to derive resolution requirements for the Short Range UAV.

IMAGERY INTERPRETATION REQUIREMENTS ANALYSIS

JOINT SERVICE INTERPRETATION STANDARDS

TARGET EEI - AIRFIELD	*MINIMUM RESOLUTION FEET/INCHES
1. Type	
Military/civil/joint	3 ft
2. Status	
a. serviceable/unserviceable	10 ft
b. operational	10 ft
c. status of construction/being modified/ type of modification	10 ft
d. hardened	10 ft
3. Activity	
a. aircraft - number, type, location	3 ft
b. other activity, if significant	
- include troop concentration	4 ft
- supply stocks	1 ft
4. Defenses - number, type, location	
a. anti-aircraft	2 ft
b. ground	4 ft
5. Combat Operation Facilities - number, type, location	
a. operations centers/bunker	3 ft
b. ATC - facilities	1 ft
c. auxiliary power supply	1 ft
d. communications/electronics	1 ft
6. Infrastructure	
a. runways/taxiways - orientation, dimensions, material	10 ft
b. dispersals/shelters	10 ft
c. other main buildings including hangars - purpose, location, hardening	10 ft
7. Support Facilities - permanent/temporary	
a. weapons storage	10 ft
b. POL	10 ft
c. power facilities	10 ft
d. supply	10 ft
e. other	n/a

MISSION/TARGET REQUIREMENT
CAT 01 - AIRFIELD



*Minimum resolution required to answer all EEI = 1 foot or a NIIRS of 7

1	2	3	4	5	6	7	8	9
30ft	15ft	8ft	4ft	30in	16in	8in	4in	2in

NIIRS Rating Scale

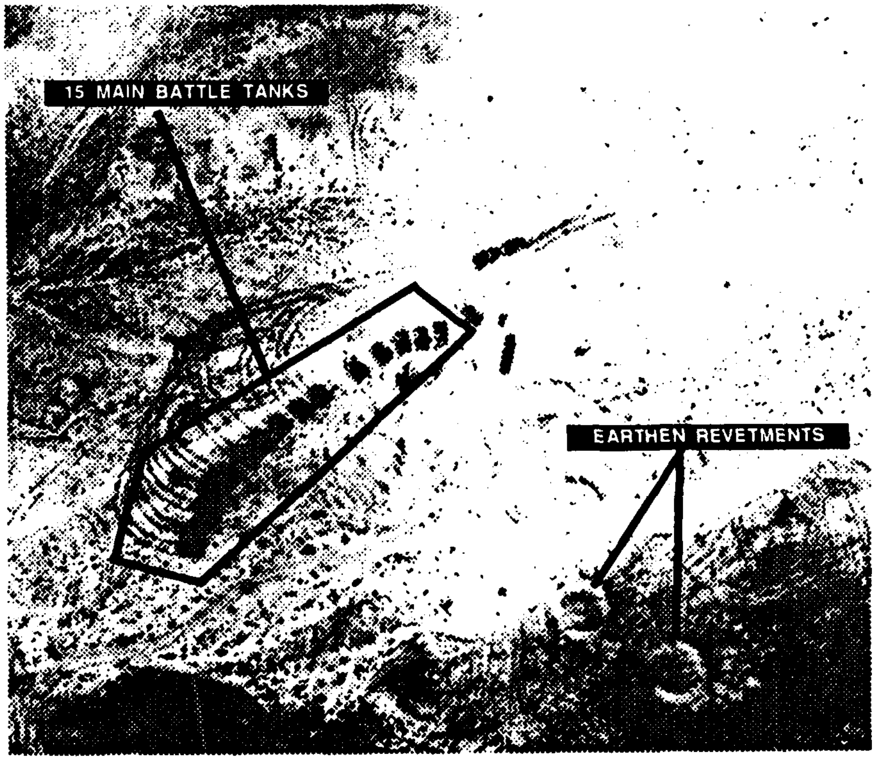
Figure 2.1-2 Requirements Analysis; Airfields

IMAGERY INTERPRETATION REQUIREMENTS ANALYSIS

JOINT SERVICE INTERPRETATION STANDARDS

TARGET EEI - MILITARY ACTIVITY	*MINIMUM RESOLUTION FEET/INCHES
1. Type	
a. mechanized/motorized infantry	1 ft
b. armour	1 ft
c. artillery - SP/field/rocket/AAA	1 ft
d. engineer	1 ft
e. helicopter/light aircraft	3 ft
f. transport/support/supply	3 ft
g. command post/field headquarters	1 ft
2. Status	
a. state of readiness/tactical formation	4 ft
b. movement - direction of movement	7 ft
c. static - dug-in, camouflaged, concealed, in firing position	4 ft
d. orientation of weapons	2 ft
3. Activity	
a. number and type	
- weapons/weapon systems	6 in
- helicopters/light aircraft	1 ft
- vehicles	1 ft
- equipment	1 ft
- personnel (if significant)	1 ft
- other military items	n/a
b. estimated number and type of tactical units (if possible)	n/a
4. Defenses - number, type, location	
a. anti-aircraft	2 ft
b. ground	4 ft
5. Terrain significant features/obstacles possibly affecting air/ground attack, e.g., minefields, hills, vegetation (only reported if specifically requested, even in code A)	5 ft

MISSION/TARGET REQUIREMENT
CAT 06 - MILITARY ACTIVITY



*Minimum resolution required to answer all EEI = 6 inches or a NIIRS of 8

1	2	3	4	5	6	7	8	9
30ft	15ft	8ft	4ft	30in	16in	8in	4in	2in

NIIRS Rating Scale

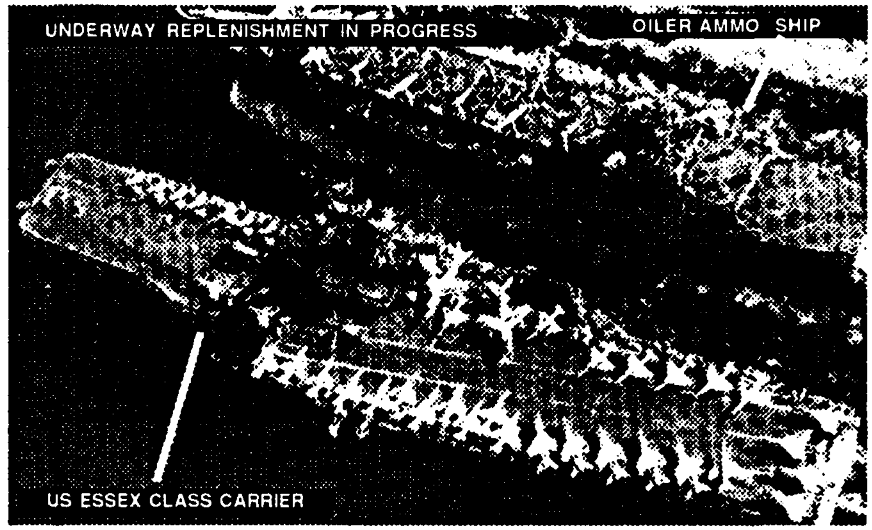
Figure 2.1-3 Requirements Analysis; Military Activity

IMAGERY INTERPRETATION REQUIREMENTS ANALYSIS

JOINT SERVICE INTERPRETATION STANDARDS

TARGET EEI - SHIPPING	*MINIMUM RESOLUTION FEET/INCHES
1. Type	
a. number of ships/craft by type (NATO code naval/merchant/auxiliary)	2 ft
b. nationality	2 ft
c. NATO class	2 ft
d. pennant number and/or name (where possible)	6 in
2. Status	
static or moving/heading and estimated speed (if possible)	15 ft
3. Activity	
tactical formation, e.g., landing operations, escort, mine laying, sweeping, replenshment at sea	2 ft
4. Defenses and armament	
a. visible aircraft/helicopters	3 ft
b. weapons number, type, location (if not standard for class/type)	6 in
5. Electronics	
number, function, type of antenna and location (if not standard for class/type)	6 in
6. Additional information	
detailed description of modifications, unusual features, etc.	6 in

MISSION/TARGET REQUIREMENT
CAT 08 - SHIPPING



*Minimum resolution required to answer all EEI = 6 inches or a NIIRS of 8

1	2	3	4	5	6	7	8	9
30ft	15ft	8ft	4ft	30in	16in	8in	4in	2in

NIIRS Rating Scale

Figure 2.1-4 Requirements Analysis; Shipping

Figures 2.1-2, 2.1-3, and 2.1-4 also show the necessary NIIRS rating for each information element and the minimum resolution needed to cover all EEI's for the target category identified. The resolution requirements listed with these target/EEI examples are for a "point target" mission and therefore the most stringent. For other mission types such as "area coverage" and "route/strip" missions, image interpreters can answer the tasked EEIs using lower quality imagery in terms of resolution.

Figure 2.1-5 contains the complete list of resolution requirements used in this study. It identifies ground resolved distances for every target category by mission type. These values set sensor resolution performance which, together with Short Range operational parameters, drive system and subsystem requirements.

Our analysis determined there are two broad categories of requirements: (1) a resolution of 6 to 12 inches (NIIRS 6-8) for the high resolution/point target tasking and (2) a resolution of 2 to 8 feet (NIIRS 3-5) for the lower resolution/area search and route reconnaissance tasking. This is because the point target tasking normally includes requirements to perform detailed analyses of the target area, while the area search tasking requires only detection and top level identification. These requirements are referenced throughout the remainder of this report and were used in the derivation and presentation of subsystem requirements.

2.2 Phase 2: System/Subsystem Analysis

The UAV Joint Program Office provided several unmanned aerial vehicle specification documents. This set of documents included the Unmanned Aerial Vehicle Master Plan, dated February 1990. Figures 2.2-1 and 2.2-2 are examples of air vehicle data in the UAV Master Plan. This information

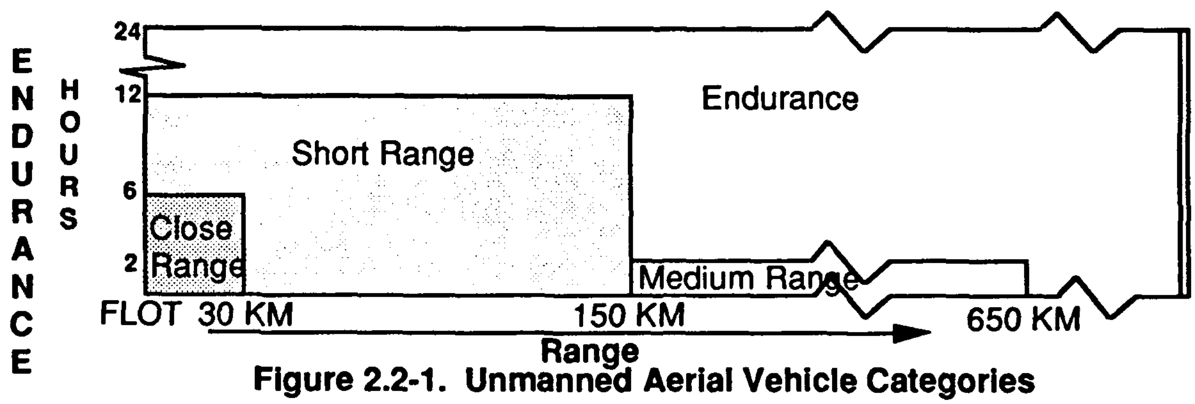


Figure 2.2-1. Unmanned Aerial Vehicle Categories

MISSION AREAS / US/NATO TARGET CATEGORIES	AREA COVERAGE MISSION (Detect - General ID)	ROUTE/STRIP MISSION (General ID - Precise ID)		POINT TARGET MISSION (Precise ID - Description - Analysis)
		Road/Rail/Canal	Coast	
01 - Airfield	15 feet			12 inches
02 - Missile Systems	5 feet			6 inches
03 - Electronic Installations	10 feet			6 inches
04 - Barracks/Camps/Headquarters	10 feet			12 inches
05 - Storage and Repair Facilities	5 feet			2 feet
06 - Military Activity	7 feet	4 feet	4 feet	6 inches
07 - River Crossings/Ferries	5 feet	2 feet		12 inches
08 - Shipping	15 feet		2 feet	6 inches
09 - Route Reconnaissance	15 feet	2 feet		
10 - Terrain Reconnaissance	300 feet		5 feet	
11 - Coastal Strip	15 feet		2 feet	
12 - Bridges	15 feet	5 feet		2 feet
13 - Water Control Facilities	20 feet	5 feet		2 feet
14 - Ports/Harbors	20 feet		5 feet	2 feet
15 - Rail Facilities	15 feet	6 feet		2 feet
16 - Industrial Facilities	50 feet			5 feet
17 - Electric Power Installations	20 feet			3 feet

Not Applicable to a Particular Mission Area

Figure 2.1-5 Minimum Imagery Resolution Requirements by Mission Area

REQUIREMENT TYPE	CLOSE	SHORT	MEDIUM	ENDURANCE
Operational Needs	Recon, Survl, Tgt Acq, Tgt Spot, EW, NBC Recon	Recon, Survl, Tgt Acq, Tgt Spot, Met, NBC Recon, Command and Control, EW	Pre-and Post-Strike Recon, Tgt Acq, Sigint, EW, Met	Recon, Surv, Tgt Acq, Command and Control, Met, NBC Recon, Sigint, EW, Special OPS
Launch and Recovery	Land/Shipboard	Land/Shipboard	Air/Land	Land
Radius of Action	None Stated	150 KM Beyond FLOT	650 KM	Classified
Speed	Not Specified	Dash >110 Knots Cruise <90 Knots	550 Knots <20,000 Ft .9 MACH >20,000 Ft	Not Specified
Endurance	1 to 6 Hours	8 to 12 Hours	2 Hours	24 Hours on Station
Info Timeliness	Real-Time	Near-Real-Time	Near-Real-Time/ Recorded	Near-Real-Time
Sensor Type	Day/Night Imaging, EW, NBC	Day/Night Imaging, Data Relay, Comm Relay, Radar, Sigint, Met, Masint, Tgt Designate, EW	Day/Night Imaging, Sigint, Met, EW	Sigint, Met, Comm Relay, Data Relay, NBC, Imaging, Masint, EW
Air Vehicle Control	None Stated	Preprogrammed/ Remote	Preprogrammed/ Remote	Preprogrammed/ Remote
Ground Station	Vehicle and Ship	Vehicle and Ship	JSIPS (Processing)	Vehicle and Ship
Data Link	Worldwide/Low-High Intensity	Worldwide/Low-High Intensity	JSIPS Interoperable Worldwide/Low-High Intensity	Worldwide/Low-High Intensity
Crew Size	Minimum	Minimum	Minimum	Minimum
Service Need/ Requirement	Army, Navy, Marine Corps	Army, Navy, Marine Corps	Navy, Air Force, Marine Corps	Army, Navy, Marine Corps

Figure 2.2-2 UAV Requirements

was used to derive the vehicle requirements for this study. System flight profiles were derived from the Lavi Technical Services report entitled "Short Range UAV Mission Description and Flight Profiles." Together these documents specify what we refer to as the "JPO requirements" or "JPO-derived requirements". Figure 2.2-3 shows an example of a Short Range mission description/flight profile. (The title includes reference to AR-S-1, which is used to denote this particular mission scenario.) These figures represent the Short Range UAV Army reconnaissance mission. This mission is one of three such reconnaissance missions exploited in the derivation of Short Range system requirements for this study.

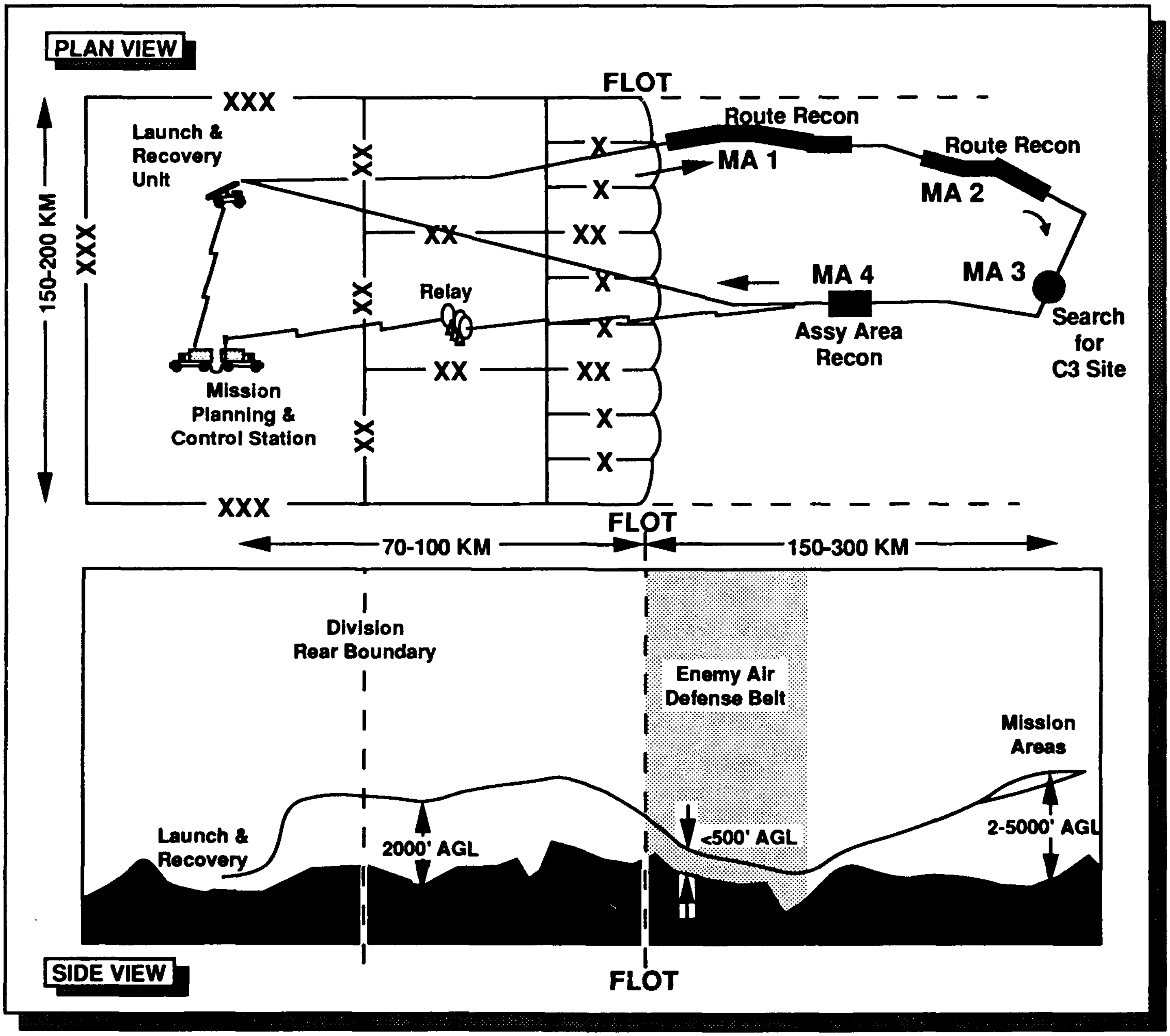
Specific documents used as sources for UAV specifications are:

(1) "Unmanned Aerial Vehicle Master Plan"; Department of Defense, June 1989 and February 1990 updates
(2) "Short Range UAV Mission Description and Flight Profiles"; Lavi Technical Services, Inc., March 1989
(3) "Unmanned Aerial Vehicle Short Range (UAV-SR) Joint Program System Specifications"; Department of Defense, July 1989

Figure 2.2-4 shows how we propagated the imagery interpretation requirements from Phase 1 through to the vehicle systems and subsystems level. It also illustrates the interdependencies among the sensor, data link, data recorder, navigation and flight control system. Some operational parameters such as vehicle speed, mission tasking, and flight profile were required. For instance, one must know vehicle ground speed together with the resolution requirement to derive a data rate for any candidate recording device and data link. In some cases, assumptions were made based on generic ranges of values provided in the references.

Figure 2.2-5 lists information under the categories of general operational specifications and performance parameters along with the sources for the data. We didn't address some categories of JPO requirements because they are not impacted by imagery interpretation analysis and/or not required as an operational assumption. For instance, the number of ground crew personnel for UAV launch, recovery, and maintenance is not a driver in imagery analysis. These categories are indicated by shaded blocks. The Joint Program Office derived specifications were generally extracted from JPO sponsored sources and then categorized with minimal analysis.

• **Short Range Army UAV Reconnaissance Mission**



• **UAV Relay is used as required by terrain, combat conditions, or weather**
• **Mission areas are approximately 50 square kilometers each**

Figure 2.2-3
Tactical Flight Profile:
AR-S-1, Reconnaissance and Surveillance

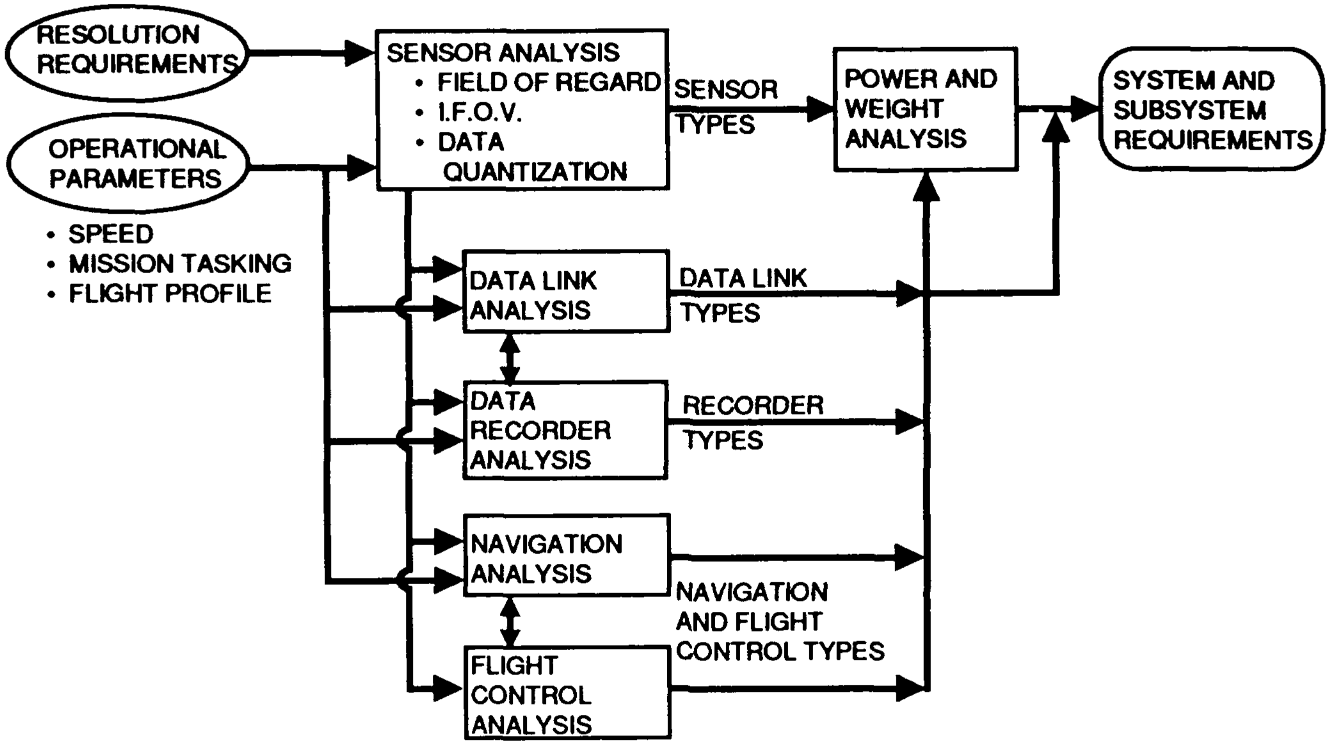


Figure 2.2-4 System Requirements Development

Requirement Type		JPO Derived Requirements	
GENERAL OPERATIONAL SPECIFICATIONS	Contracting Services	Army, Navy, Marine Corps	(1)
	Operational Utility	Recon, Surveil, Tgt Acq, Tgt Spot, Met, NBC Recon, C2, EW	(1)
	Mission Area Requirements	All Mission Areas and Reconnaissance Types Related to the Mission Specified in "Operational Utility"	(1)
		Perform Route Reconnaissance, Search for/Monitor C3 Site, Assembly Area, or Airfield, Detect Surface Action Group, Monitor Surface Ship	(4)
	Air Vehicle Control	Preprogrammed/Remote	(1)
	Ground Station Center	Vehicle, Ship, and Remote	(2)
	Launch and Recovery	Land/Shipboard	(1)
	Crew Size	Medium	(1)
	Radius of Action	•150 km beyond FLOT	(1)
		•300 km beyond FLOT - Goal	(2)
PERFORMANCE PARAMETERS	Speed	Dash - >110 knots Cruise - <90 knots	(1)
	Endurance	8-12 hours	(1)
		90 min loiter at max range	(3)
	Altitude	Two Loiter Altitudes: 1000' & 1200' Above Ground Level (AGL)	(3)
	Information Timeliness	Near Real Time	(1)
SYSTEMS AND SUBSYSTEMS	Sensor Type/Capability	Day/Night Imaging, Data Relay, Comm Relay Radar, SIGINT, Met, MASINT, Tgtdsnt, EW	(1)
	Sensor Internal Communications	•Two Internal Video Busses •30 MHz Analog Bus - Goal	(3)
	Data Link	•World wide/Low-High Intensity	(1)
		•10.71 MBPS P 50 km, 10.71 MBPS @ 123 km w/o Relay, Omnidirectional	(3)
	Image Data Recorder (Rate and Volume)	Not Specified	
	Navigation/Control System	Preprogrammed/Remote	(1)
	Communications	Mk-12 IFF with III-C and IV Codes	(3)
	Payloads (Power and Weight)	Max Weight 100 lbs, Max Power 1000 Watts, Max Volume 2000 cubic inches	(3)
	Air Vehicle Gross Take-Off Weight (Driven by Payload)	Not Specified	

▭ NOT A DRIVER IN IMAGERY ANALYSIS

SOURCES:
(1) "UNMANNED AERIAL VEHICLE MASTER PLAN", FEBRUARY 1990
(2) "UNMANNED AERIAL VEHICLE MASTER PLAN", JUNE 1989
(3) "UNMANNED AERIAL VEHICLE SHORT RANGE (UAV-SR) JOINT PROGRAM SPECIFICATIONS", JULY 1989
(4) "SHORT RANGE UAV MISSION DESCRIPTION AND FLIGHT PROFILES", MARCH 1989

Figure 2.2-5 Short Range UARV Requirements

2.2.1 Mission-Critical Systems

The primary factors which define image quality are resolution, dynamic range, and coverage. (Other factors, such as image anomalies and geometric distortion, are of secondary importance and are primarily driven by sensor characteristics.) The first two are defined as mission critical and the latter as vehicle critical. As a result, we identified three mission-critical systems that impact image quality; the sensors, data link and data recorder. The analysis of the sensors imposes requirements on the other two mission critical systems.

2.2.1.1 Sensors

The JPO Short Range UAV mission requirements include reconnaissance, surveillance, target acquisition, and target spotting and designation. This is specified for both day and night time applications. This study utilized only those Short Range applications defined for reconnaissance.

2.2.1.1.1 Assumptions

The sensor requirements the *JPO outlined for reconnaissance* missions (shown previously in Figure 2.2-5) are not sensor specific and call only for "day/night imaging." Therefore, we assume sensor concepts that fulfill day/night imaging requirements; i.e., small gimballed forward looking infrared systems (FLIRs), infrared line scanners (IRLS), and electro-optical line scan and framing (television) cameras (EOCAM). Each of these highly diverse imaging systems has unique characteristics pertinent to this study.

Other sensors may, in the future, be incorporated into the UARV system to provide additional capability. These sensors include three dimensional laser radars, and a wide variety of radio frequency (RF) radar sensors. The laser radar could provide both intensity and range information for target areas and shows high promise for use in locating targets under foliage or camouflage. This sensor can also be used in all lighting conditions (day/night) since it is active and provides its own illumination source. It is however, limited to good visibility conditions.

RF sensors, however, readily penetrate most visual obscurants, but due to aperture versus wavelength limitations, radar systems are generally limited in resolution. Synthetic aperture (sidelooking) and holographic (downward looking) radars overcome this limitation somewhat by synthesizing longer apertures, but require extensive processing and motion compensation. Since neither of these

technologies is adequately mature to meet the total requirements of the Short Range UAV reconnaissance mission, they will not be discussed further in the analysis. We reserve additional discussion for the future technology assessment in section 4.

The Advanced Tactical Air Reconnaissance System (ATARS) program will use both infrared and electro-optic line scan reconnaissance systems for its baseline. The high performance, high resolution sensors in development for ATARS are improved versions of the existing operational and demonstration prototypes. Both existing and improved line scan imaging sensors were analyzed as payloads for this study.

In Phase 1, based on published NATO and US reconnaissance standards, we concluded GRDs of 6 to 12 inches (NIIRS 6-8) are required to satisfy the reporting of all of the EEIs derived for point target tasking. The results of Phase 1 also lead to the conclusion that a GRD of 2 to 15 feet is sufficient for area search and route reconnaissance tasking.

In addition to GRD, one must also define reasonable limits for the third dimension of an image representation, the number of gray scale tones representing an image. The number of gray scale tones sets a maximum data word length that is to be transmitted at each resolution cell (pixel). For example, an 8-bit data word corresponds to 2^8 or 256 quantization levels. The number of image bits, along with signal bits needed for communications and the rate of collection, set requirements for the data link, internal data busses, and image data recorder.

Research reported by Dr. S. J. Briggs of Boeing Aerospace and Electronics concluded that the average person can discriminate approximately 500 gray shades (8.23 bits) and that a 95th percentile person can discriminate 860 gray shades (9.75 bits). (Reference "Soft Copy Display of Electro-Optical Imagery". SPIE proceedings Volume 762, 1987.) The study cited used conservative assumptions. Murch and Weimar of Tektronics Corp estimated that 11.41 bits (2721 gray levels) are required to optimize detectability of detailed information on a high resolution display system (Reference "Gray Scale Requirements for Complex Images", Society for Information Display Digest of Technical Papers, Volume XXI, May 1990). Several earlier research studies concluded that no subjective increase in image quality occurs beyond 5 to 6 bits of gray scale input. Measurements of high quality operational intelligence community displays showed that even with 8 bit inputs, the actual display output only 5 to 6.5 bits. Thus current display technology, not the interpreter's eyes, is the limiting factor. Based on these diverse inputs, we assumed that 8 bits of data quantization per pixel is the minimum image data quantization, with 10 bits as the desirable goal and reasonable upper limit. This range appears consistent with the display

improvement trends that will ultimately impact newer ground station systems, like the Joint Services Imagery Processing System (JSIPS).

Data compression analyses were outside the scope of this study. An introduction of lossless data compression would typically provide at best a 4:1 compression ratio and would require additional hardware for encoding the image data. By assuming no data compression, the upper limit of the data rate was evaluated.

Figure 2.2-6 summarizes the generic sensors used to derive further subsystem requirements. The figure shows the resolution capabilities of these systems as well as other associated features. Both the high resolution and lower resolution class sensors have reasonable quantization capability. Weight and power data is necessary to determine total payload weight and power requirements. In addition, the maximum altitude allowed to achieve four different resolution levels is given for each sensor category. Figure 2.2-3, shown previously, outlined nominal altitudes of 2000-5000 feet for reconnaissance operations for the Short Range UAV Army mission areas specified by the Joint Program Office. Comparing these altitude requirements shows the "higher performance class" sensors are able to achieve the desired resolution (NIIRS 6-8) from these altitudes, while the "lower performance class" sensors can only achieve lower resolution (NIIRS 3-5) at operational altitudes close to those desired. Although the lower class sensors could fly lower to achieve the higher resolutions, the swath width is impacted significantly, as shown (Figure 2.2-6). This directly impacts the number of passes over each area to obtain the desired coverage. Typically 30 percent swath sidelap is required for complete coverage.

2.2.1.1.2 Forward Looking Infrared (FLIR)Systems

FLIRs are typically used in an oblique mode to search for targets, navigation identification check-points, and obstacles or hazards to flight. Optical framing sensors, such as televisions, operate in the same manner as FLIRs but are limited to daylight operation. Since the visual systems offer no additional capability, the remainder of the discussion will focus on the FLIR. The FLIRs are usually used in real-time with a person-in-the-loop monitoring the image. In addition, they have limited sensor fields-of-view (SFOV). A wide SFOV FLIR typically has a 20 degree by 15 degree SFOV while a narrow SFOV is typically only approximately 3 by 2 degrees. In many cases, the aspect ratio is maintained at 4 by 3 (widthby height) to allow for display on a standard video display. Some FLIRs also have multiple SFOVs accomplished by step zoom lenses. Automatic target tracking algorithms can track an object of interest such as a military vehicle as the FLIR approaches and overflies the object of interest. Laser target designation for weapon deliveries can be accomplished during this target closure sequence.

Sensor Description		Maximium altitude to achieve NIIRS at NADIR* / Total Swath Width — NIIRS Scale (Resolution): 7 - 8 (6")	6 - 7 (12")	5 - 6 (24")	3 - 4 (60")	Weight/Power
Lower Performance Class Sensors (data quantization 7-8 bits)	Electro-optical camera (0.5 mrad resolution, 140 degree SFOV)	1000 ft / 5495 ft	2000 ft / 10990 ft	4000 ft / 21980 ft	10000 ft / 54950 ft	25 lbs/90 watts
	Infrared line scanner (0.5 mrad resolution, 120 degree SFOV)	1000 ft / 3464 ft	2000 ft / 6928 ft	4000 ft / 13856 ft	10000 ft / 34641 ft	30 lbs/300 watts (goal)
	FLIR, 875 lines/frame (0.5 mrad resolution, ~22 by 30 degree SFOV)	1000 ft / 389x 536 ft	2000 ft / 778x 1072 ft	4000 ft / 1555x 2144 ft	10000 ft / 3888x 5359 ft	50 lbs/500 watts
Higher Performance Class Sensors (data quantization 10-12 bits)	Electro-optical camera (0.2 mrad resolution, 140 degree SFOV)	2500 ft / 13737 ft	5000 ft / 27475 ft	10000 ft / 54950 ft	25000 ft / 137374 ft	40 lbs/300 watts
	Infrared line scanner (0.25 mrad resolution, 120 degree SFOV)	2000 ft / 6928 ft	4000 ft / 13856 ft	8000 ft / 27713 ft	20000 ft / 69282 ft	76 lbs/300 watts
	FLIR, 1250 lines/frame (0.1 mrad resolution, ~5.9 x 7.8 degree SFOV)	5000 ft / 515x 682 ft	10000 ft / 1031x 1363 ft	20000 ft / 2061x 2727 ft	50000 ft / 5153x 6817 ft	75 lbs/800 watts (maximum)

* For comparison purposes, these altitudes reflect sensor operation in vertical mode at NADIR. Targets imaged with depression angles other than 90 degrees will have lower resolution.

Figure 2.2-6
Capabilities of the Generic Sensors used in the UARV Study

In the search mode described above, the FLIR is typically used in the forward sector at depression angles from 0 degrees (horizontal) to 30 degrees. Figure 2.2-7 illustrates the theoretical performance of a 0.5 mrad FLIR. For a generic 0.5 mrad (instantaneous field-of-view) FLIR at altitudes of 500 to 1000 feet, these depression angles correspond to a resolution capability of between a NIIRS 3 (5 degrees depression angle, 1000 foot altitude) to NIIRS 7 (25 degrees depression angle, 500 foot altitude). Depression angles of at least 22 degrees are required to achieve NIIRS 6 at a 1000 feet altitude. To calculate these values, one determines the slant range, $\mathbf{R_S}$, to the point of interest with the equation,

$$R_s = \frac{H}{\sin \partial}$$

where **H** is the altitude above ground level (AGL), and ∂ is the depression angle. One can then use the equation,

$$\mu = 2R_s \tan\left[\frac{IFOV}{2}\right]$$

to solve for the resolution, μ, at the altitude and depression angle desired where **IFOV** is the angular instantaneous field of view. This theoretical performance assumes the system can correct for low altitude flight induced dynamics (e.g., high velocity to height ratios, V/H, which can cause image motion during the scan) and optical effects. The FLIR gimbals can be preprogrammed to perform the necessary side-to-side rotating sweep to build up the required area coverage below the UAV. However, this procedure compromises the high value features of the FLIR by requiring this frame imaging sensor to approximate line scanner dynamics. In order to provide the same coverage as line scan sensors, this, by definition, increases the data rates and quantity since the FLIR repeatedly scans essentially the same scene (usually at 60 times per second). The frame to frame overlap means that where line scan sensors image a particular point once, the FLIR is imaging each point many times and the duplicative data must be handled. In most cases, the data rates are limited, thereby sacrificing total data collection.

The gimballed FLIR has been purposely designed for a class of tactical target acquisition missions, such as navigation and weapons delivery. The FLIR has an extremely valuable role in the Short Range UAV, and can be used for a multitude of purposes, including the reconnaissance mission. The single sensor can be used in a scanning mode to perform area and route search, in the oblique mode to compensate for navigation errors, and to focus on specific targets of interest both by preprogramming and

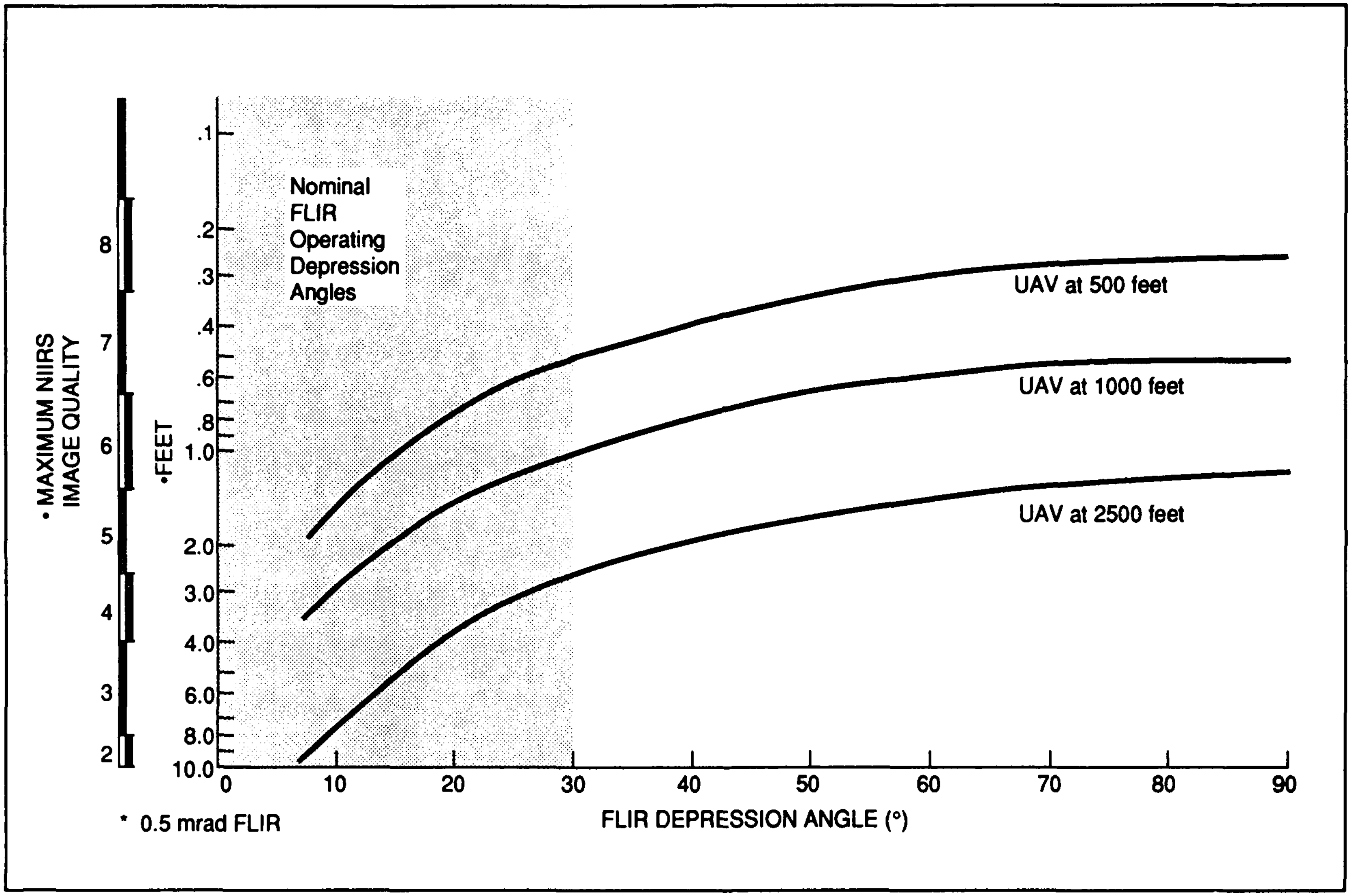


Figure 2.2-7
Theoretical Maximum Image Quality vs FLIR Depression Angle

by real time control, when available. These reconnaissance roles are in addition to any roles requiring it for navigation and/or terrain avoidance.

2.2.1.1.3 Line Scan Systems (EO/IR)

The generic class of downward looking sensors develop imagery by scanning the area passing below the vehicle. Two approaches are commonly used to accomplish this process. A line scanning sensor uses a very limited number of detectors (normally 1-12) and mechanically scans the instantaneous field of view in a cross-track direction. The pushbroom sensor uses a large linear array with direct optics to generate the cross track resolution. In both cases, the forward motion of the reconnaissance platform provides the scan in the along track axis of the image. When combined with a wide angle cross track sensor field of view, the continued operation of the sensor during movement provides the area coverage imagery. The predominant sensor technology in use is the line scan system since the pushbroom sensors require large arrays, nominally one detector for each cross track resolution element. The development of linear arrays with thousands of elements, all possessing approximately the same responsivity is challenging the state-of-the-art. As such, the sensors available are principally line scanners.

Line scan imagery possesses many unique attributes. Imagery is generated while scanning in one direction and moving in another. Therefore, the images of points at one end of a scan are not taken at the same point in space as images of points at the other end of the same scan. When placed in a line to form an image, the result is distortions which increase with distance from the NADIR line (the line on the ground directly beneath the flight line). These distortions can be corrected prior to image display, but if not, can affect the image quality as perceived by the image interpreter.

Since line scanners image a particular point only once, the sensor can collect much larger areas at the desired resolution without excessive data quantities or rates. These line scanners do not, however, allow for searching for targets of interest or target lock-on, as is possible with a FLIR. Line scan systems can fulfill Short Range UAV mission requirements by utilizing two altitudes, fields of view, or if necessary two sensors. The wide sensor field of view would be used to accomplish the area and route searches, while the narrow sensor field of view provides the point coverage. The advantage of the line scanner is its ability to provide high resolution, large sensor field of view imagery within the minimum possible bandwidth.

2.2.1.2 Data Link and Image Data Recorder

We quantified each of the basic reconnaissance mission area tasks in terms of total data storage required and image data generation rate. Although the Short Range UAV Army mission was used as a baseline for the quantification of these parameters, we also compared the Navy and Marine Short Range missions and determined them to be similar as shown in Figure 2.2-8. This figure also summarizes the required total data storage and data generation rates for the Short Range reconnaissance mission areas. Note that for the purposes of this analysis, the mission areas requiring imagery with 2 foot resolution or greater were covered with the lower resolution infrared line scanner. Those requiring one foot or better were covered with the high resolution scanner. The difference is a factor of two in resolution and number of pixels per scan line (the sensor fields of view were kept constant), and two additional bits of dynamic range.

The total storage requirement for each line is based on the storage of only the target scene as defined. No overlap, end lap, or excess for start/stop was included. We calculated the value for the linear targets (route recon) by determining the number of pixels linearly along the path and multiplying by the number of pixels in the scan line. This gave the total number of pixels, which we then multiplied by the quantization to get the number of bits. The area targets were calculated by dividing the area by the resolution squared to determine the number of pixels and then multiplying by the quantization. The number of bits is divided by 10^6 to determine Mbits. (It is important to remember to use like quantities (e.g. all feet) when performing the calculations.) These equations are as follows:

Linear Targets:

$$\text{Bits} = (L/\mu)\ (P_{ix})\ (B_p)$$

Area Targets:

$$\text{Bits} = [(L)(W)/\mu^2]\ (B_p) \quad .$$

In these equations, **L** is the length of the target area, **W** is the width (for area targets), P_{ix} is the number of pixels per scan line, μ is the resolution, and B_p is the quantization in bits per pixel. The maximum requirements that result are 27.8 Mbps with 13.8 x 10^3 Mbits total storage for single targets.

We determined the final system requirements by examining the possible mission scenarios. One must sum the individual target areas during a sortie in order to establish a requirement for the total storage capacity. The missions are as defined in Figure 2.2-8. If a "low resolution mission" is assumed to be four

- Tactical reconnaissance and surveillance mission AR-S-1 as baseline

Target Task Analyzed	Similar Mission		Sensor	Total Storage Requirement (Mb)	Data Rates - Mbps
	U.S.M.C.	U.S.N.			
MA-1 Route Recon 70 km long with 2 foot resolution	MA-3	Yes	Current IR Line Scanner; 0.5 mrad IFOV ~120 degree SFOV 4096 pixels/line 8 bits/pixel	3.76×10^3	2.78
MA-2 Route Recon 120 km long with 2 foot resolution	MA-3	Yes		6.45×10^3	2.78
MA-3 Search for C3 site. Search 50 sq. km at 5 foot resolution	MA-1	Detect shipping & enemy surface action group		172	1.11
MA-4 Search 40 km by 100 km for military assembly areas - 5 foot resolution	MA-2	Yes		13.8×10^3	1.11
MA-3 Monitor C3 site 200 m x 200 m at 1 foot resolution	MA-1	Yes	High Performance IR Line Scanner; 0.25 mrad IFOV ~120 degree SFOV 8192 pixels/line 10 bits/pixel	4.31	13.9
MA-4 Monitor 5 sub-areas 2 sq. km each at 6 inch resolution	MA-2	Monitor surface ship and airfield		861 /tgt 4.31×10^3 total	27.8

Notes:
- UARV imaging at 100 kts (170 fps)
- Total Storage is for target area only
- Data Rate is based on proper V/H compensation

Low Resolution Requirement driver

High Resolution Requirement driver

Figure 2.2-8
Imagery Data Generation Rates & Storage Requirements

area searches (the maximum storage requirement), and ten percent is added to allow for early start and late stop and thirty percent for sidelap, the total storage requirement for the mission becomes 78.9×10^3 Mbits of data storage. The "high resolution" mission is defined as the five high resolution targets and one 120 km route reconnaissance (recalculated for the higher sensor performance). The point targets require a considerable overhead, since the targets do not fill the sensor field of view and some extra must be included on the ends to account for the navigation inaccuracy. The extra data will be collected and therefore a multiplier of 2 is applied to the quantity calculated for these targets. The result is 24.74×10^3 Mbits for the high resolution monitoring.

We performed the rate calculations by making some simplifying assumptions. First, the sensor can exactly compensate for V/H variations. This leads to perfectly square pixels at the nadir. Second, we assume that the overhead data (e.g. sync pulses, auxiliary data) are inconsequential. This allows the calculation to be performed by dividing the velocity by the resolution to determine the number of scan lines per second, and then multiplying by the number of pixels per scan line. By then multiplying by the quantization, the data rate in bits per second is determined. This relates the data rate directly to the resolution. This is reasonable since in practice the data rate is determined by V/H and resolution is determined by altitude. In the example in Figure 2.2-8, the velocity is fixed, and the desired resolution determines the altitude. This is represented by,

$$R_d = (V/\mu)\ (P_{lx})(B_p)$$

where R_d is the data rate and V is the platform velocity. This provides the rate during sensor operation, and though the average rate may be lower due to inactive times during turn around, this is the rate required for recorders and data links. It should be noted that the data rate shown in the figure is quite low due to the resolution and velocity chosen. With 100 knots and an altitude of 4000 feet (determined by the 2 foot resolution, see Figure 2.2-6), the V/H ratio is .043. Many sensors cannot image at that rate due to lower limits of scan speed. The AN/AAD-5 IR scanner, for example, has a lower limit of .05. If the sensor were at 2000 feet altitude, providing one foot resolution, the V/H ratio would be .085, and the data rate would be a factor of two higher, or 5.56 Mbits per second. As a result, the recommended minimum rate capability for the "low resolution" scenario is 6 Mbps. The "high resolution" case is much more straightforward. The driving scenario uses six inch resolution at an altitude of 2000 feet, again a V/H of .085. The rate of 27.8Mbps is a reasonable value for reference.

Real time imagery especially from FLIR and television sensors is relayed by both analog and digital data links. Digital data links tend to allow greater image fidelity and can be essentially "transparent". Digital

links provide greater noise immunity than analog systems, but require larger bandwidths than analog systems. Other benefits of digital over analog systems exist in the areas of cost, maintenance, and modularity. Based on these benefits and since the image data must be eventually digitized anyway for near real time digital display systems designed for digital imagery formats, we focus on digital data links throughout the remainder of this analysis.

Figures 2.2-9 and 2.2-10 summarize the data link and tape recorder technologies the study team evaluated, including typical weights for these subsystems we used in the payload and vehicle weight analysis. The 10.71 Mbps data links accommodate the low resolution applications and those capable of up to 274 Mbps for the high resolution requirements. Although the data rate available in the high resolution systems is an overkill for the UARV applications, it is a straight forward modification to reduce the rate. MIL-STD-2179 recorder technology can meet the storage requirements and data rates. Even though the capabilities of MIL-STD-2179 recorders far exceed what's required, this technology is the only one that meets the rate and volume requirements.

Figure 2.2-11 shows storage capacity versus weight trends for the tape recorder technologies summarized in Figure 2.2-9. This provides a graphical comparison between classes of tape recorder technologies. Although MIL-STD-2179 recorders and the ATARS data link readily meet the data rate and volume requirements for the Short Range UARV mission, both units are relatively large and heavy. Some variant of these units, compatible with the larger units, could meet UAV-SR requirements and at the same time provide reconnaissance system interoperability. This interoperability would allow UARV imagery to be used in any ATARS compatible reconnaissance ground station, including those designated for manned systems.

2.2.2 Vehicle-Critical Systems

2.2.2.1 Navigation

The third factor of image quality described earlier (see paragraph 2.2.1) is coverage. A NIIRS 9 image is no good if it does not properly cover the target area. In addition, a good coverage is required for many targets because the EEIs included reporting elements of the area surrounding the primary target, including ground and air defenses and support activity often nearby such as power supply or communications. Without the proper coverage, none of these can be reported. As such, it is critical that the vehicle be navigated to the correct position to take the image.

Data Link Technology		Data Rates and * Transmit Mode	Weight (lbs) *
High Resolution Reconnaissance	High resolution, high bandwidth reconnaissance system (Digital unit)	274 Mbps directional 70 watts transmit	82.8
		274 Mbps directional 10 watts transmit	62.6
	ATARS class	137 or 274 Mbps directional, 2 antennas	82.1
Low Resolution Reconnaissance	Mini data links (current generation)	10.71 Mbps omni directional	31
		10.71 Mbps omni directional	25
Lowest Resolution Reconnaissance	Other existing data links (Aquila generation and others)	9.4 Mbps	20
		4.5 Mbps	30
		3.4 Mbps	35
		4.6 Mbps	60 to 76 anti-jam margin dependent

* Manufacturer-provided data referenced in Section 6.0

Figure 2.2-9 Data Link Capabilities Overview

Tape Recorder Technology		Data Rates *	Total Bits *	Weight (lbs) *
High Resolution Recorder	High resolution ATARS class helical scan (MIL-STD-2179 class)	40, 60, 80, 120 Mbps variable with external clock	3.4×10^{11} bits	63.2
			3.4×10^{11} bits	83.5
			1.9×10^{12} bits	75
Low Resolution Recorder	Analog television recorders (RS-170 TV)	Based on analog video - equated as digital 3 Mbps	3.3×10^{12} bits	9.8
			1.25×10^{10} bits	24.5
			1.75×10^{10} bits	30
			3.25×10^{10} bits	30
			6.5×10^{10} bits	15.5
Simplest System	Telemetry data recorders ([illegible]cal mini unit)	1.536 Mbps	2 hrs data 1.1×10^{10} bits	3.3

* Manufacturer-provided data referenced in Section 6.0

Figure 2.2-10 Current Tape Recorder Technologies Summary

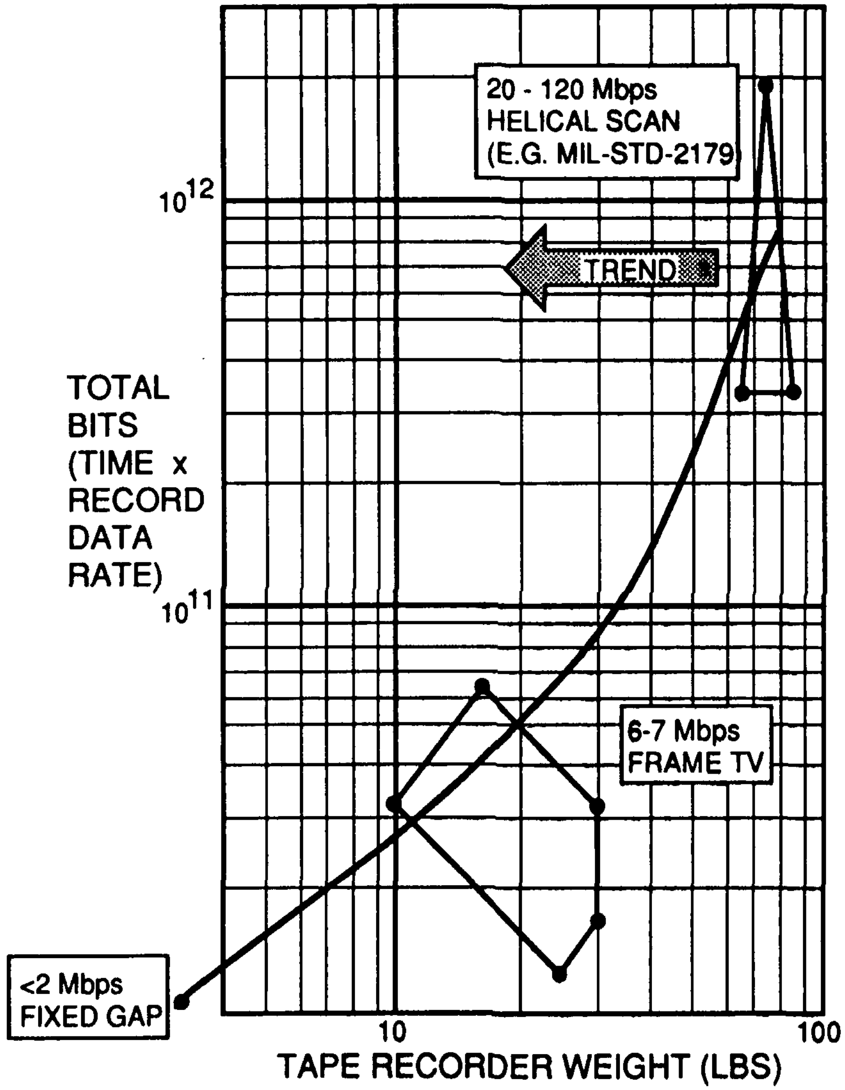


Figure 2.2-11
Digital Image Tape Recorder Trends: Storage Capacity vs. Weight

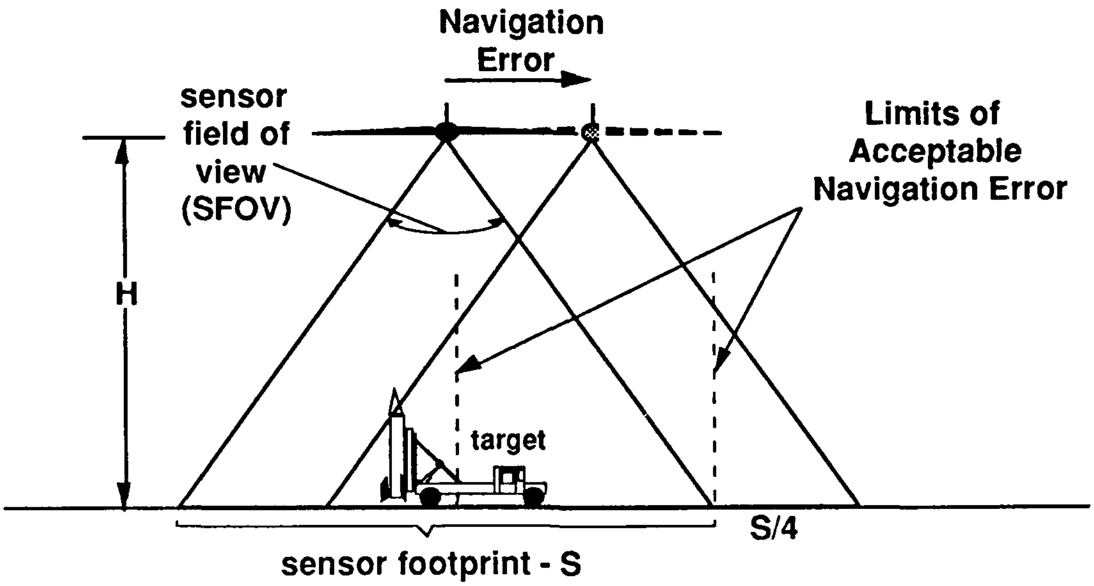


Figure 2.2-12
Navigation Accuracy versus Sensor Field Of View

A key consideration when deriving navigation accuracy requirements is the imaging sensor total field of view. Figure 2.2-12 shows this relationship for the cross track accuracy. The along track accuracy generally equals the cross track accuracy and is not the limiting factor since the sensors are generally turned on well before the actual target and turned off well after (as measured relative to cross track accuracies). The sensor ground footprint, **S**, is determined with the equation,

$$S = 2H \tan\left[\frac{SFOV}{2}\right]$$

where **H** is the altitude (AGL), and **SFOV** is the angular sensor field of view. The study team derived these navigation accuracies to assure target coverage within the central 50 percent of the coverage swath. This limits the resolution degradation due to slant range effects and the perspective distortion due to seeing the object obliquely. The greatest navigation error allowed, therefore, is one-fourth of the sensor footprint or,

$$\text{nav error}_{MAX} = \frac{S}{4} = \frac{H}{2} \tan\left[\frac{SFOV}{2}\right]$$

By inserting the appropriate altitude and sensor field of view, the allowable navigation error can be determined. For example, given an altitude of 1000 feet and an SFOV of 140 degrees, the navigation

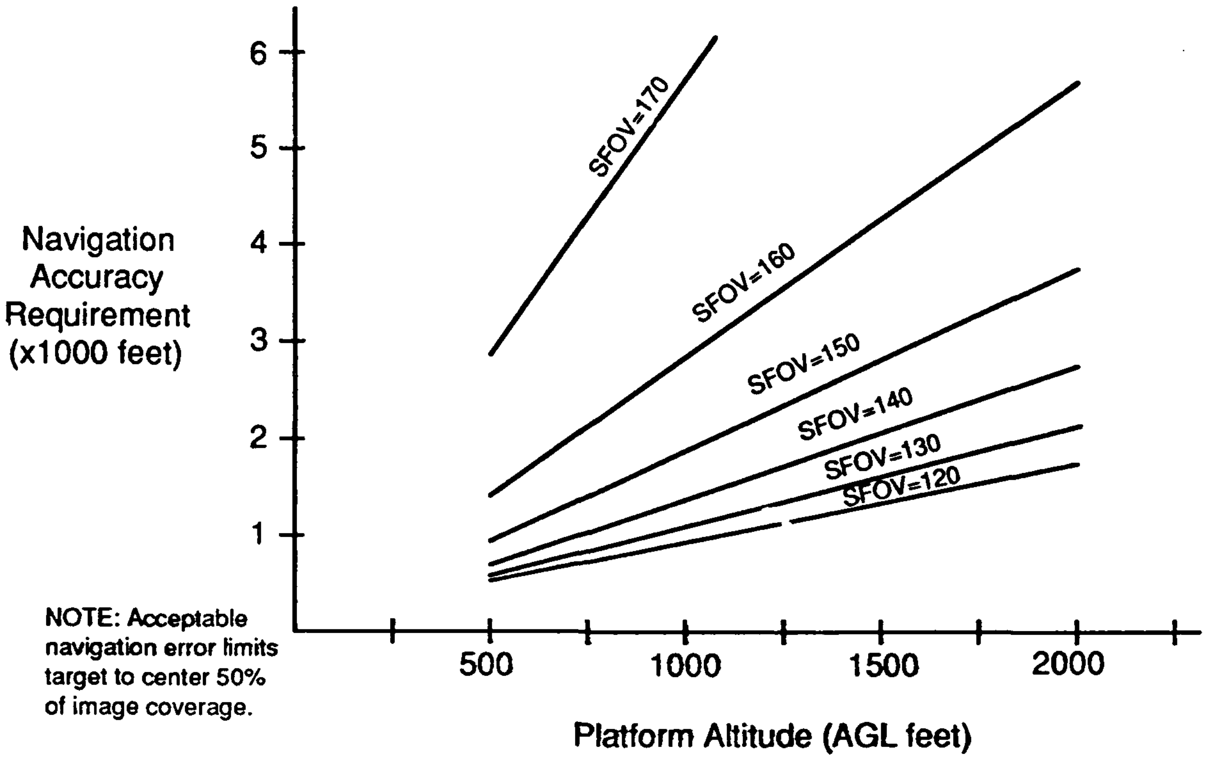


Figure 2.2-13
Sensor Field Of View Relationship to Navigation Accuracy

accuracy requirement is less than 1400 feet. Figure 2.2-13 plots the values for various sensor fields of view.

After review of the navigation accuracy capabilities, we concluded that the 0.8 to 1.0 NM drift per hour, common in the general class of standard navigation units, does not meet the navigation accuracy necessary for UARVs to do high resolution imaging. The basic inertial navigation system (INS) must be augmented with auxiliary systems to update the position data. One option is augmenting the INS with a Doppler radar to determine the cross track drift and/or add a radar altimeter. This, however, would consume excessive amounts of the power and weight budgets with weights of 50-60 pounds and power requirements of 200-300 Watts and only provide limited accuracy improvements. A second potential enhancement is the emerging class of standard navigation units with Global Positioning System (GPS) capabilities embedded in the unit. This would save power and weight over the previous option and provide GPS accuracies measured in tens of feet. Another solution is to use terrain contour matching systems developed for the cruise missile. These systems are very complicated. The mission planning takes weeks for analysis and programming for every mission. Due to the limits this would place on the flexibility of the UAV and the high cost of these systems, the study team recommends more conventional

approaches such as a miniaturized embedded-GPS/INS system that would furnish GPS navigation functions with a significantly reduced size, weight, and power. A developmental DARPA program, entitled "GPS Guidance Package" (GGP), will develop a small, accurate guidance system using miniaturized GPS receivers integrated with fiber-optic gyroscope based inertial measurement units. The goal in this program is to provide a unit of about 10 pounds and 30 Watts of power consumption.

2.2.2.2 Flight Controls

Government and industry programs have demonstrated the basic UAV flight control-autopilot systems successfully in the variety of UAV's. currently flying. Maintaining the UAV flight path to the precisions previously discussed requires close coupling and integration between the GPS-augmented inertial measurement unit and the autopilot-flight control system core computer. This integration is best accomplished using the MIL-STD-1553 data bus and interfaces. UARV's should benefit from emerging digital avionics systems development trends and incorporate those standards which enhance interoperability, maintainability, reliability, and equipment availability. In addition, there is interest in standardizing the input interfaces to the flight control systems, namely the command link and mission support system. These are discussed further in Section 3.4.3.3, Interoperability.

The analysis done for the study estimated that appropriate digital autopilots for UARV applications weigh 30 lbs and require 300 watts. This core system weight does not include the navigation subsystem weights previously discussed.

2.2.3 Integrated Systems

The study specifies power and weight requirements as a separate "integrated technology". We constructed a weight buildup using data discussed in the previous sections. Figure 2.2-14 shows weights for two classes of UARV payloads, NIIRS 3-5 and NIIRS 6-8. As illustrated, high resolution tasking requires much higher weight systems compared to low resolution systems. The associated power analysis yielded a 980 watt requirement for the lower resolution payload, and upwards of 2 kw for the high resolution payload. The payload buildups shown in this figure do not reflect combining the EOCAM and IRLS system capabilities since this would impose additional weight and power penalties. (The operational ATARS system for manned aircraft deployment may carry both sensors simultaneously.)

Payload weight has a direct impact on the total gross take-off weight (GTOW). Figure 2.2-15 shows the trend of this relationship based on existing UARV's. Although general in nature, this data

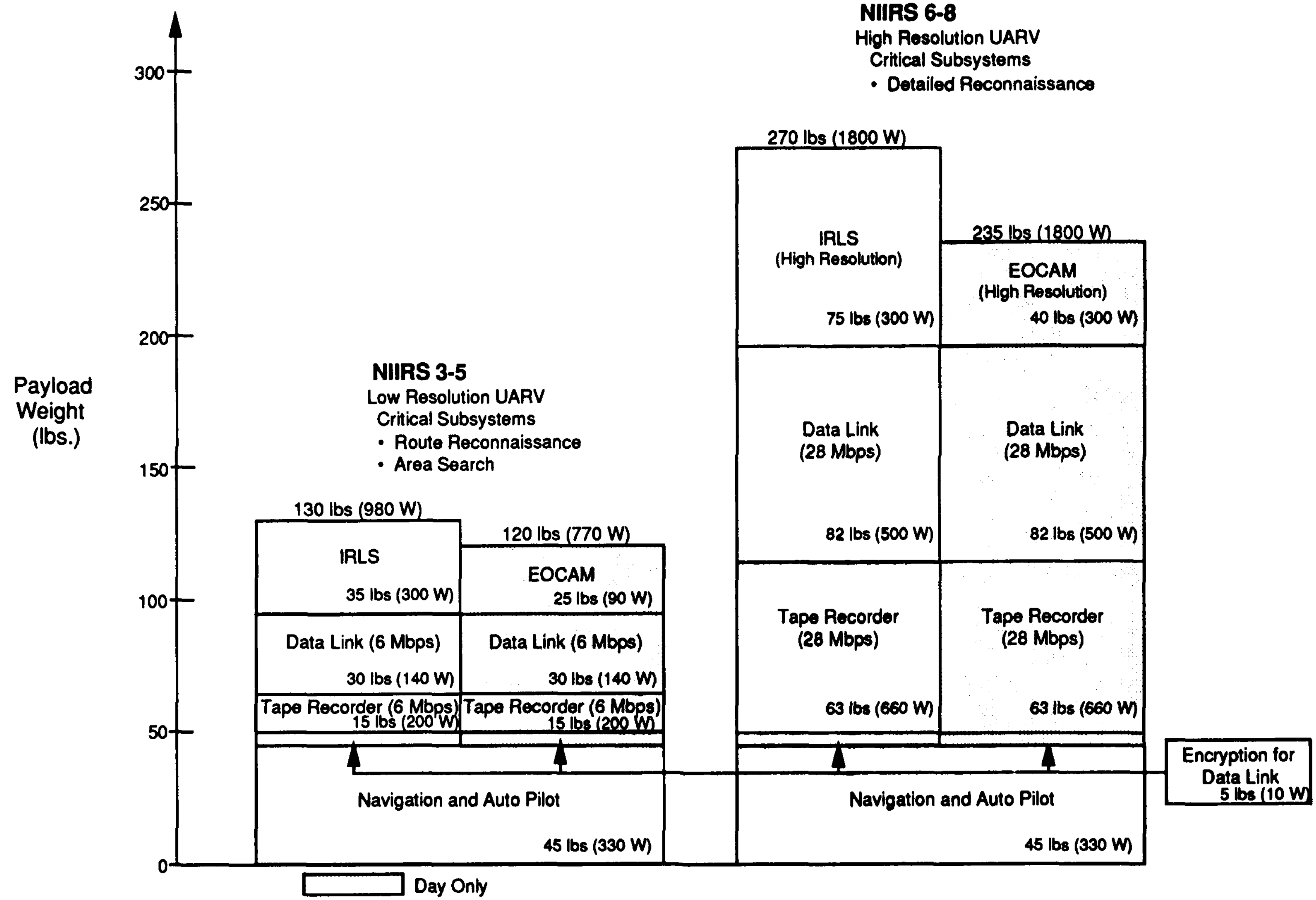


Figure 2.2-14
Reconnaissance Systems Weight Build-up Summary

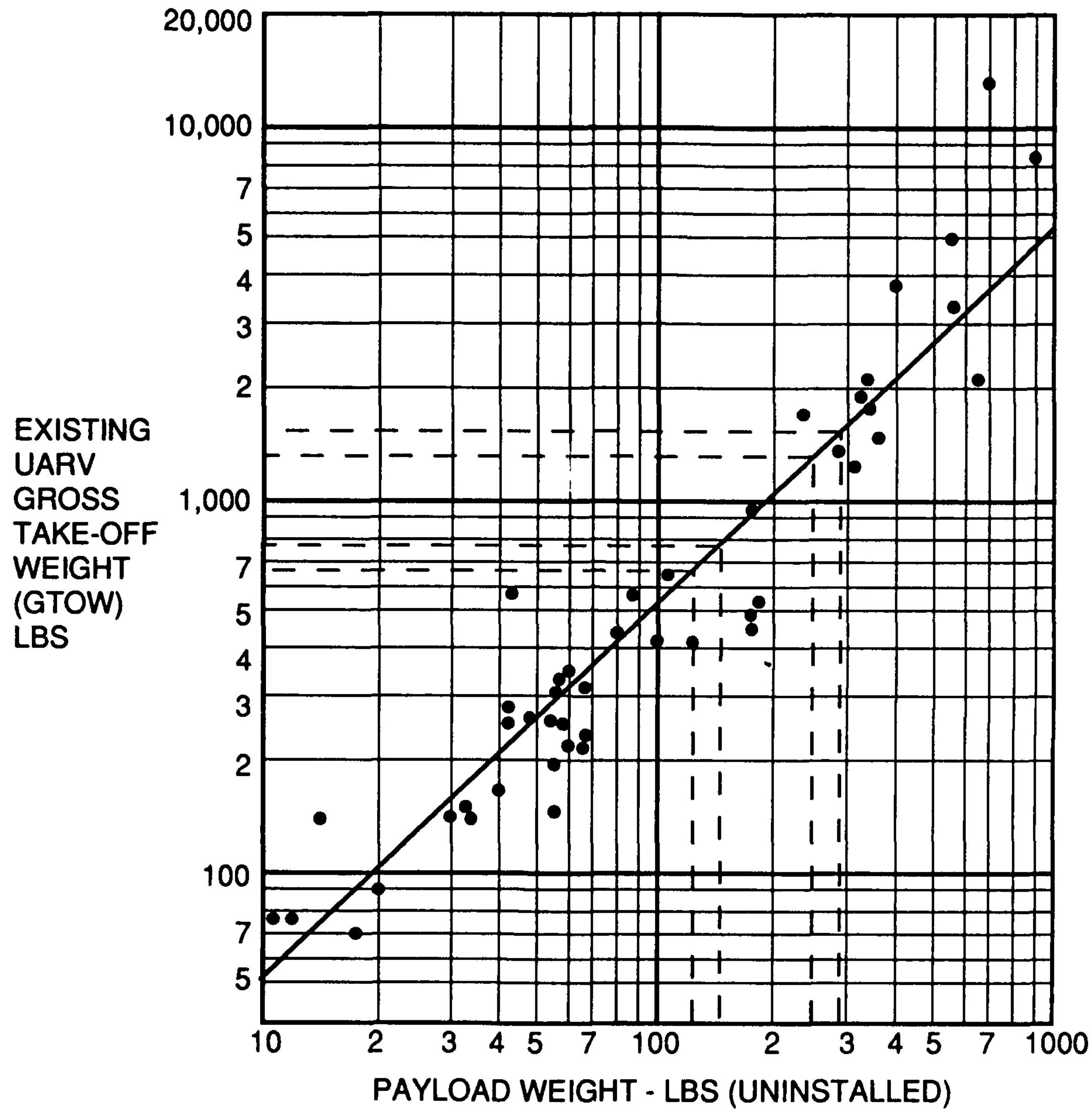


Figure 2.2-15
Payload to Vehicle Size Comparison Data

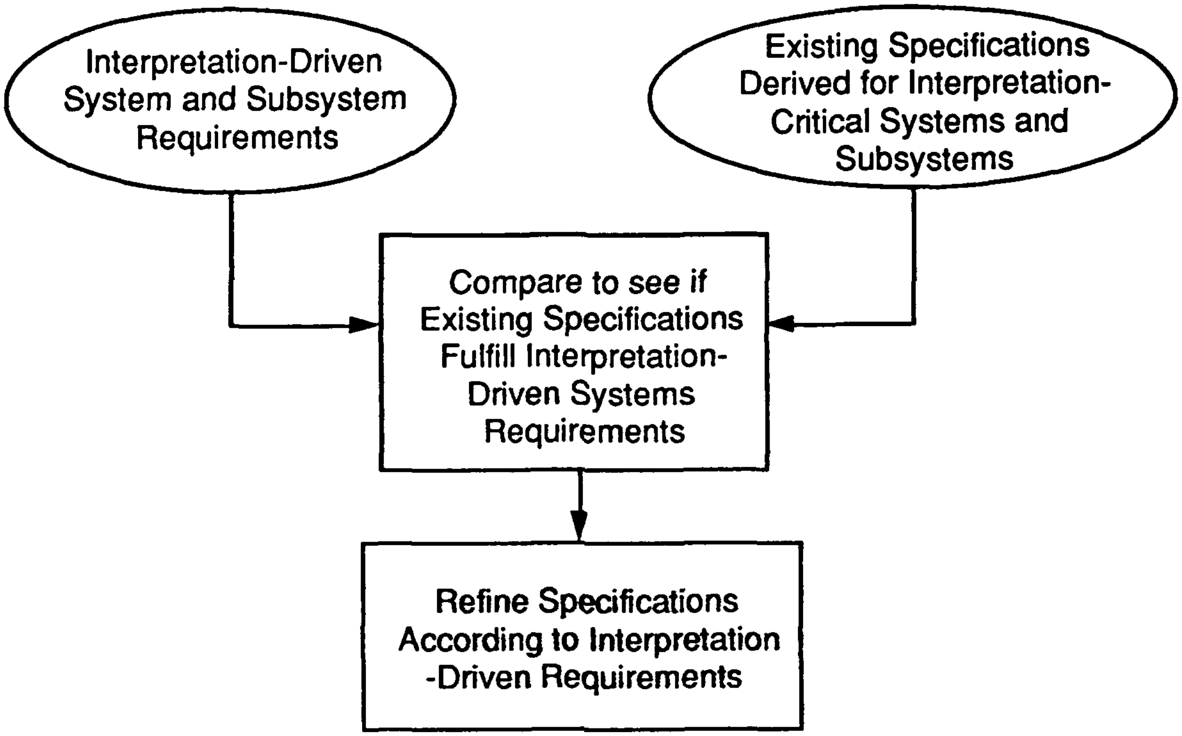


Figure 2.3-1
Requirements Refinement Methodology

provided useful information to assess the resulting estimated UARV gross take-off weight. As shown, the low resolution system would have a GTOW of approximately 700-800 pounds, while the high resolution system would be 1200-1400 pounds.

2.3 Phase 3: UARV Payload Refinement

Figure 2.3-1 illustrates the comparison and revision process used to arrive at a refined set of UARV payload component specifications. Figure 2.3-2 expands upon Figure 2.2-5 (shown earlier) and summarizes JPO, II, and the refined requirements for the Short Range UARV. As before, we examined only components/subsystems relevant to the image interpretation task.

2.4 Phase 4: Technology Assessment

To this point, we identified what the Short Range payload should look like based on interpretation driven image requirements. In general, current technology capabilities and trends make these payloads

Requirement Type		JPO Derived Requirements		Imagery Interpreter Driven Requirements: Search & Route Reconnaissance	Imagery Interpreter Driven Requirements: Detailed Reconnaissance	Refined UARV Requirements: Search & Route Reconnaissance	Refined UARV Requirements: Detailed Reconnaissance
GENERAL OPERATIONAL SPECIFICATIONS	CONTRACTING SERVICES	ARMY, NAVY, MARINE CORP	(1)				
	OPERATIONAL UTILITY	RECON, SURVIL, TGT AQU, TGT SPOT, MET NBC RECON, CC, EW	(1)	RECONNAISSANCE *	RECONNAISSANCE *	RECONNAISSANCE · PERFORM ROUTE	RECONNAISSANCE
	MISSION AREA REQUIREMENTS	ALL MISSION AREAS AND RECONNAISSANCE TYPES RELATED TO THE MISSION SPECIFIED IN "OPERATIONAL UTILITY"	(1)	PERFORM ROUTE RECONNAISSANCE (4) * SEARCH FOR C3 SITE, SEARCH FOR ASSEMBLY AREA, DETECT SURFACE ACTION GROUP, SEARCH FOR AIRFIELD	MONITOR C3 SITE, MONITOR (4) * ASSEMBLY AREA, MONITOR SURFACE SHIP, MONITOR AIRFIELD	RECONNAISSANCE SEARCH FOR C3 SITE, SEARCH FOR ASSEMBLY AREA, DETECT SURFACE ACTION GROUP, SEARCH FOR AIRFIELD	MONITOR C3 SITE, MONITOR ASSEMBLY AREA, MONITOR SURFACE SHIP, MONITOR AIRFIELD
	AIR VEHICLE CONTROL	PREPROGRAMMED/REMOTE	(1)	PREPROGRAMMED AND REMOTE * CAPABILITY	PREPROGRAMMED AND REMOTE * CAPABILITY	PREPROGRAMMED AND REMOTE CAPABILITY	PREPROGRAMMED AND REMOTE CAPABILITY
	GROUND STATION CENTER	VEHICLE, SHIP, AND REMOTE	(1)				
	LAUNCH AND RECOVERY	LAND/SHIPBOARD	(2)				
	CREW SIZE	MEDIUM	(1)				
	RADIUS OF ACTION	· 150 KM BEYOND FLOT · 300 KM BEYOND FLOT - GOAL	(1) (2)				
PERFORMANCE PARAMETERS	SPEED	DASH>110 KNOTS, CRUISE<90 KNOTS	(1)	100 KNOTS (GROUND SPEED) *	100 KNOTS (GROUND SPEED) *	100 KNOTS (GROUND SPEED)	100 KNOTS (GROUND SPEED)
	ENDURANCE	8-12 HRS 90 MIN LOITER AT MAX RANGE	(1) (3)				
	ALTITUDE	TWO LOITER ALTITUDES STUDIED: 1000,1200 FT ABOVE GROUND LEVEL	(1)	ALTITUDES TO 30KFT FOR LOW RES WIDE AREA SEARCH	ALTITUDES 290 FT TO 2000 FT FOR HIGH RES. MONITORING	ALTITUDES TO 30KFT FOR LOW RES WIDE AREA SEARCH	ALTITUDES 290 FT TO 2000 FT FOR HIGH RES. MONITORING
	INFORMATION TIMELINES	NEAR REAL TIME	(1)	NEAR REAL TIME *	NEAR REAL TIME *	NEAR REAL TIME	NEAR REAL TIME
SYSTEM AND SUBSYSTEMS	SENSOR TYPE/CAPABILITY	DAY/NIGHT IMAGING, DATA RELAY, COMM RELAY, RADAR, SIGINT, MET MASINT, TGTDSNT, EW	(3)	DAY/NIGHT IMAGING SENSORS: IRLS & EOCAM @ 1/4 TO 1/2 MRAD RESOL FLIR @ 1/4 MRAD RESOL (OPTIONAL)	DAY/NIGHT IMAGING SENSORS: IRLS & EOCAM @ 1/10 MRAD RESOL FLIR @ 1/10 MRAD RESOL (OPTIONAL)	IRLS & EOCAM @ 1/4 TO 1/2 MRAD RESOL; FLIR @ 1/4 MRAD RESOL (OPTIONAL)	IRLS & EOCAM @ 1/10 MRAD RESOL; FLIR @ 1/10 MRAD RESOL (OPTIONAL)
	SENSOR INTERNAL COMMUNICATIONS	TWO INTERNAL VIDEO BUSSES (GOAL 30 MHZ ANALOG BUS)	(3)	6.0 MBPS	27.8 MBPS	6 MBPS SENSOR DATA BUS	28 MBPS SENSOR DATA BUS
	DATA LINK	· WORLD WIDE/LOW-HIGH INTENSITY · 10.71 MBPS P 50 KM, 10.71 MBPS @ 123 KM W/O RELAY, OMNI-DIRECTIONAL	(1) (3)	6.0 MBPS (MIN)	27.8 MBPS (MIN)	SECURE DATA LINK WITH 6 MBPS RATE (MIN)	SECURE DATA LINK WITH 28 MBPS DATA RATE (MIN)
	IMAGE DATA RECORDER (STORAGE AND RATE)	NOT SPECIFIED		6.0 MBPS/7.89 E10 BITS	28 MBPS/8.62E10 BITS TOTAL	6 MBPS/7.89E10 BITS TOTAL STORAGE	28 MBPS/8.62E10 BITS TOTAL STORAGE
	NAVIGATION/CONTROLS SYSTEMS	PREPROGRAMMED - REMOTE	(1)	· NAV ACCURACY + 5080 FT FOR 5 HRS · V/H MEASURED ± 3% · ALT HOLD 500 FT ABOVE GROUND LEVEL	· NAV ACCURACY 7520 FT FOR 5+ HRS · V/H MEASURED TO ± 5% · ALT HOLD 500 FT ABOVE GROUND LEVEL	INS WITH UPDATE FROM 1) GPS OR 2) RADAR ALTIMETER WITH DOPPLER RADAR	INS WITH GPS UPDATE, RADAR ALTIMETER AS BACKUP
	COMMUNICATIONS	MK-12 IFF WITH II-C AND IV CODES	(3)				
	PAYLOADS (POWER & WEIGHT)	MAX WEIGHT 100 LBS, MAX POWER 1000 WATTS VOLUME 2000 CUBIC INCHES	(3)	PME TO 130 LBS & 980 WATTS (MIN) **	PME TO 270 LBS & 1800 WATTS (MIN) **	PME TO 130 LBS (MIN) AND ** 980 WATTS (MIN)	PME TO 270 LBS (MIN) AND ** 1800 WATTS (MIN)
	AIR VEHICLE GROSS TAKE-OFF WEIGHT (DRIVEN BY PAYLOAD)	NOT SPECIFIED		~770 LBS **	~1400 LBS **	~770 LBS **	~1400 LBS **

SOURCES:
(1) "UNMANNED AERIAL VEHICLE MASTER PLAN," FEBRUARY 1990
(2) "UNMANNED AERIAL VEHICLE MASTER PLAN," JUNE 1989
(3) "UNMANNED AERIAL VEHICLE SHORT RANGE (UAV-SR) JOINT PROGRAM SPECIFICATIONS," JULY 1989
(4) "SHORT RANGE UAV MISSION DESCRIPTION AND FLIGHT PROFILES," MARCH 1989

(shaded) NOT A DRIVER IN IMAGERY ANALYSIS

** REQUIREMENTS BASED ON CURRENT TECHNOLOGY TRENDS

* NOT DERIVED DIRECTLY FROM IMAGERY REQUIREMENTS, BUT USED AS AN OPERATIONAL ASSUMPTION TOGETHER WITH THE RESOLUTION REQUIREMENTS TO DRIVE OTHER SUBSYSTEMS

Figure 2.3-2
Short Range UARV Refined Requirements

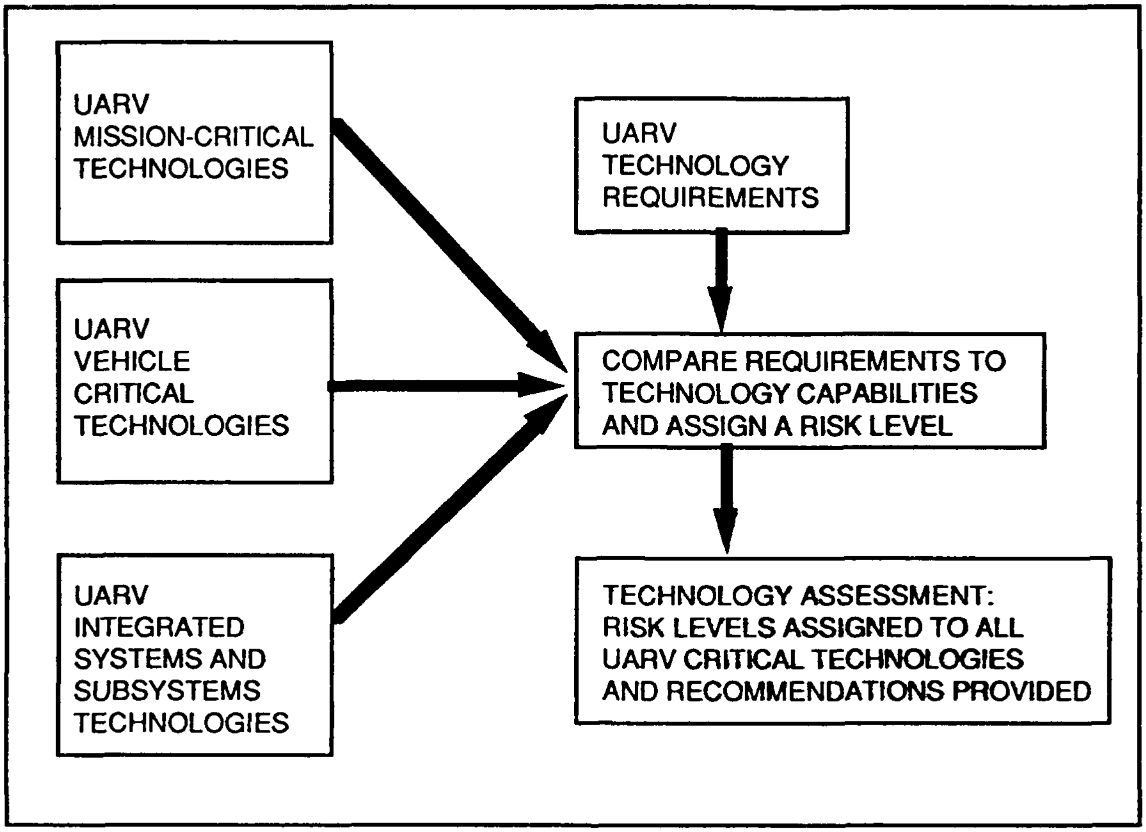


FIGURE 2.4-1
Technology Assessment Process

feasible. However, government and industry must push technology in some areas. The following sections assess the risk of technology providing acceptable payloads (from an II's point of view) within reasonable time and cost constraints.

Four categories of risk represent the research and development that must occur to provide the Short Range payloads an II needs to do his job. A "1" was assigned to the highest risk level, component/system requirements not supported by current technology; a "4", the lowest risk level went to off-the-shelf technology that could meet the payload requirements with little or no modification. Figure 2.4-1 summarizes the technology assessment process.

Figures 2.4-2, 2.4-3, and 2.4-4 summarize the assessment of UARV required technologies and are discussed in detail in the following sections. It is worth noting here that no UARV critical technology

identified by this study warrants the highest level of risk. Rationale is provided on which the assessment was made as well as a recommended course of action. These recommendations are again summarized in the Results and Conclusions section. We grouped several technologies into two categories, "low resolution" and "high resolution" indicating their tasking application, since requirements and the resulting associated technology risk are different for these two kinds of tasking.

2.4.1 UARV Mission-Critical Technologies

Figure 2.4-2 summarizes the risk assessment of the UARV mission-critical technologies identified in the study. A detailed explanation of each technology area follows.

2.4.1.1 Sensors

The government can satisfy low resolution imaging requirements with current EO/IR, state-of-the-art imaging sensors having 120 to 140 degree sensor field-of-view and 1/4 to 1/2 mrad resolution. However, these sensors are slightly heavier than desired. Since payload weight drives vehicle size (and ultimately cost) we recommend a weight reduction program for these current state-of-the-art sensors. FLIR area search sensors having 1/4 to 1/2 mrad resolution also satisfy the near-term low resolution requirements for the UARV, but these systems are very expensive for UARV applications and are also heavier than desired. In summary, although today's technology supports the near-term low resolution (NIIRS 3-5) UARV requirements, the government should push both weight and cost reduction efforts. Therefore, we assigned this effort a risk level of 3.

The high resolution technology must address various improvement efforts to allow image interpreters to answer EEIs requiring NIIRS 6 to 8 resolution. This requires technology improvement programs to achieve at least 1/10 mrad resolution for both the EO and IR sensors. These improved sensors still must maintain the 120 to 140 degree sensor field of view due to the interactions of navigation accuracies and assured target sensor coverage. Currently forecasted or prototype sensors having these resolution/coverage parameter capabilities are considerably larger than desired. Therefore, the government should undertake programs to minimize size, weight, power and cost for the improved (NIIRS 6 to 8) imaging sensors in parallel with sensor technology improvement. Accordingly, we assigned this performance improvement effort a level 2 risk, indicating present technology would support this goal, if so directed.

Technology Risk: Highest (1) to Lowest (4)

1. Present technology will not support
2. Present technology would support if directed
3. Off-the-shelf with minor adaptation
4. Off-the-shelf technology

Based on the Short Range UARV

Technology Area		Requirement	Risk Assessment	Risk Assessment Rationale	Recommendation
Sensors	LR	• Wide Angle - 120° to 140° field of view • 1/4 mrad resolution • Minimum weight	3	• Technology for line scan EO/IR reconnaissance systems well in hand. Emphasis on tailored UARV systems required. • Gimballed mini FLIR/TV systems currently quite expensive for performance obtained.	• None required; Weight reduction desired.
	HR	• Wide angle 120° to 140° field of view • 1/10 mrad resolution • Minimum weight	2	• Both EO/IR line scan reconnaissance system & gimballed sensors (FLIR/TV) are currently costly & heavier than desired for UARV deployment.	• Cost & weight reduction for high resolution sensors
Data Link	LR	• 6 Mbps • Minimum weight	4	• The 10.71 common data link in development is adequate.	• Continue development of 10.71 Mbps data link to reduce weight
	HR	• 28 Mbps • Minimum weight	3	• The data link technology will readily support 28 Mbps version of CDL. This is product emphasis more than a technology issue.	• Support development of a 28 Mbps version of the common data link
Image Data Recorder (Storage & Rate)	LR	• 6 Mbps/7.89 x 10^4 Mb total storage • Minimum weight	3	• Digital tape recorders based on MIL-STD-2179 providing lower data rates are possible using 8 mm tape.	• Continue development of a MIL-STD-2179 8 mm recorder fully compatible with the standard
	HR	• 28 Mbps/8.62 x 10^4 Mb total storage • Minimum weight	3	• The interoperable MIL-STD-2179 tape recorder should be used which provides only the necessary data rate while maintaining interoperability.	• Continue development of a MIL-STD-2179 8 mm recorder fully compatible with the standard

LR = Low Resolution Mission (NIIRS: 3 to 5)
HR = High Resolution Mission (NIIRS: 6 to 8)

Figure 2.4-2
Technology Assessment: UARV Mission - Critical Technologies

2.4.1.2 Data Links

For low resolution imaging systems, the common data link (CDL) program is addressing a 10.71 Mbps digital data link based on preliminary UARV requirements. This data rate satisfies the near- term lower requirements of 6 Mbps for the Short Range UARV and is assigned a risk level of 4.

Deploying improved high resolution reconnaissance systems satisfying NIIRS 6 to 8 performance goals requires a 28 Mbps data link. To satisfy this objective, a miniaturized, low cost version of the common data link should be developed. Data link technology readily supports the 28 Mbps rate; what is required is a specific program to develop a data link consistent with the size, weight, power and cost guidelines for UARV equipment. The government should incorporate this effort within the CDL program. Since present technology would support this need if funded and directed, a level 3 risk has been assigned.

2.4.1.3 Image Data Recorders

Using low resolution imaging sensors imposes a data link requirement of 6 Mbps data rate. Further, the volume of data requires a total storage capacity (in bits) for the UARV image data tape recorder of 7.89×10^4 Mb. MIL-STD-2179 incorporates the three sizes of SMPTE D-1 tapes as well as an 8 mm tape. The 8 mm version can meet these requirements, but it would be advantageous to limit the capabilities of the UARV machines to the data rates required, thereby offering potential size, weight, and cost savings. Such a program represents redirection of off-the-shelf technology, and therefore we assigned a risk of 3.

The high resolution sensors require a higher performance unit of 28 Mbps data rate with 8.62×10^4 Mb of storage. The full MIL-STD-2179 helical scan digital image tape recorder in development exceeds the UAV-SR requirement and could be too heavy and costly for UAV-SR deployment. Therefore, as above, the technology recommendation is to explore the 8 mm version of the 2179 tape recorder to fulfill the requirement. Since the 8 mm recorder technology would support this requirement with tailored capability reductions, a risk level of 3 is assigned.

2.4.2 UARV Vehicle-Critical Technologies

A detailed explanation of the assessment made for the navigation and flight controls technologies as shown in Figure 2.4-3 follows.

Technology Risk:

Highest 1. Present technology will not support
2. Present technology would support if directed
3. Off-the-shelf with minor adaptation
Lowest 4. Off-the-shelf technology

Based on the Short Range UARV

Technology Area	Requirement	Risk Assessment	Risk Assessment Rationale	Recommendation
Navigation	GPS accuracy, lightweight	2	GPS upgrades to standard nav. units are still large & heavy. DARPA's "GPS Guidance *Package" is addressing system* $\leq$ 10 lbs.	Integrate DARPA "GGP" research into the UAV interoperable architecture program
Flight Control	Must be augmented with high accuracy navigation system or radar altimeter/doppler radar unit	4	Off-the-Shelf technology meets requirements	No further action required (see Interoperability section)

Figure 2.4-3
Technology Assessment: UARV Vehicle-Critical Technologies

2.4.2.1 Navigation

All UARV applications require navigation system accuracies in excess of those attainable with the standard navigation units currently in inventory. Global Positioning System (GPS) information could augment these systems to achieve the necessary accuracies. GPS is the only positioning system that could provide such accuracies with practical cost/payload constraints. For this reason, the capability of obtaining and integrating GPS information into the navigation system is essential for UARV applications.

Current Air Force standard navigation unit upgrades are addressing the re-manufacturing of units to increase reliability and decrease alignment times. Several of these "re-manufactured" upgrades will offer an option of including an integrated GPS inertial measurement unit. Nevertheless, the overall class of standard navigation units are larger and heavier than desired for UARV applications. The DARPA program addressing development will use a fiber optic gyro (FOG) to yield a miniature (10 lbs or less) inertial measurement unit (IMU) and integrated GPS/IMU/data processor with Kalman filter for a broad spectrum of DoD applications. This unit would satisfy the UARV requirement if available. We assigned a risk assessment of 2 because of the newness of this program.

2.4.2.2 Flight Controls

The requirement for an autopilot and flight control system for any UARV is imperative. The government and industry have demonstrated all key elements of digital flight control systems and have incorporated some in a few UAVs. Because this hardware is essentially available off-the-shelf, a risk of 4 (lowest risk) is assigned to this technology area.

2.4.3 Integrated System/Subsystem Technologies

A detailed explanation of the assessment (See Figure 2.4-4) made for each integrated system technology follows.

2.4.3.1 Power

The Short Range UAV currently plans to generate or make excess electrical power of up to 1000 watts available for the reconnaissance primary mission equipment (PME). The low resolution PME total power requirement analyzed in this study to be 980 watts matches the proposed available power very well

Technology Risk: Highest ↕ Lowest

1. Present technology will not support
2. Present technology would support if directed
3. Off-the-shelf with minor adaptation
4. Off-the-shelf technology

Based on the Short Range UARV

Technology Area		Requirement	Risk Assessment	Risk Assessment Rationale	Recommendation
Power	LR	980 watts	4	• Planned UAV's having UARV potential application developed for up to 1KW electrical power.	No further action required
	HR	< 2 kwatts	3	• Power extraction potential (electrical) from planned UAV engine may require higher potential output generators within current generator envelopes consistent with smaller UAV engines (General Electric and Sunstrand Samarium Cobalt Class Generators)	Develop increased power generator capacity on designated UARV
Weight	LR	130 lbs	4	• Payload capacity designated for UARV is adequate.	No further action required
	HR	270 lbs	2	• Current weight estimates for suitable UARV reconnaissance payloads exceed UARV capacity.	Initiate weight reduction program
Interoperability	Data Links	Make interoperable across U.S./NATO systems	3	• CDL is emphasizing 10.71 mbps and an ATARS 120 Mbps common data link. 28 Mbps is not a technical issue but needs emphasis.	Accelerate the common data link (CDL) program consistent with NATO IDL study
	Image Data Recorder	Make interoperable across U.S./NATO systems	3	• ATARS/2179 class tape recorder addressing 120 Mbps rates. A subset derivative of 2179 needs technology development emphasis rather than new research	Examine potential MIL-STD-2179 derivative tape recorder: 8mm version
	Flight Control Command Link	Make interoperable across U.S./NATO systems	3	• UAV autopilot command links available from multiple services and manufacturers are not interoperable.	Develop a standard UARV command link consistent with UAV interoperable architecture

LR = Low Resolution Mission (NIIRS: 3 to 5)
HR = High Resolution Mission (NIIRS: 6 to 8)

Figure 2.4-4
Technology Assessment: Integrated System/Subsystem Technologies

(and thus warrants the lowest risk category of 4). The high resolution PME approaches an estimated 2 kw in power requirement. Redesign of engines to accommodate larger or additional electrical generators is an expensive engineering problem. The use of generators using samarium cobalt magnets could allow more electrical power within an existing generator's physical envelope, (i.e., form-fit and function interchange). However, this class of generators has typically been either very large, developed for fighter class engines, or very small, directed at compact generators of less than 500 watts. Analysis and potential engineering development should address the super generator issue to ensure that the UAV engine, gearing, and power take off provisions could sustain greater capacity electrical generators. This is important on smaller UAV engines. This power issue is given a risk assessment of 3, since the technology is in place and can be adapted to a solution.

2.4.3.2 Weight

The low resolution PME weight estimated in this study is consistent with the proposed payload capacity for the Short Range UAV used for analysis. However, the estimated high resolution PME weight exceeds the specified weight and could drive the Short Range UARV to a larger vehicle than currently anticipated. The government should initiate a weight reduction program to achieve usable high resolution PME. A risk of 2 has been assigned since the weight reduction combines elements of equipment redesign and combination.

2.4.3.3 Interoperability

The requirement for interoperability impacts several technology areas. It is desirable to make them interoperable across US/NATO reconnaissance systems. Requirements for interoperability are stated in various Program Management Directives (PMDs) and policy documents, including those of NATO. Interoperability of reconnaissance assets allows force multiplication and deployment flexibility. The result is greater quality/timeliness of the intelligence to commanders at all levels of the conflict.

Rome Lab is currently conducting the "UARV NATO Interoperability Design Study (UNIDS)" to examine the required level of interoperability for UARVs based on operational requirements and practicality (cost versus benefits). Some areas being examined include the items previously discussed (image data links and recorders) as well as the command aspects. Two areas are of interest. The first is the actual command link for real time control of the UARV. If each link is unique, the ground station becomes a vulnerable "weak link" in the system. The second is the mission support system. This is the equipment

complement used to program the UARV. The study team recognizes potential advantages in flexibility if these items were standardized and recommends commonality wherever practical.

2.4.3.3.1 Data Links

The common data link (CDL) program is addressing a 10.71 Mbps version based on preliminary Short Range UAV requirements. Data links exist having data rates in multiples of 10.71 Mbps (21.42 Mbps, 32.13 Mbps, 42.84 Mbps, etc., up to 274 Mbps). One of these units could readily be aligned with the requirements for the CDL program to satisfy this UAV-SR 28 Mbps requirement. The interoperability recommendation is to accelerate the CDL program, consistent with the NIIDLS report.

2.4.3.3.2 Recorder

The Short Range UARV requires a tape recorder compatible with the 28 Mbps image data rate and data link. A relaxed requirement version of the ATARS/MIL-STD-2179 tape recorder, using the 8 mm tape, would be consistent within the goals of interoperability allowing varied commands and forces to exchange imagery data tapes. This is considered a level 3 risk.

2.4.3.3.3 Flight Control Command Links

All the key elements of digital flight control systems have been demonstrated and even incorporated into a few UAVs. It appears quite consistent with the concept to focus on a generic control system command link having the broadest possible UARV applications. This would entail defining the link in a MIL-STD covering all relevant layers of the ISO Open Systems Interconnect (OSI) model. In addition, the mission support systems, used to program the flight paths and target areas, is a candidate for standardization. This would require MIL-STDs as well. This area is assigned level 3 risk since it would require both engineering adaptation and funded direction and effort.

2.4.3.3.4 Imagery Format

In addition to common transmission modes (tape and data link), interoperability requires standard imagery formats. NATO is currently developing STANAG 7023, "Air Reconnaissance Imagery Data

Architecture". Image format can affect payload requirements by adding bandwidth overhead for auxiliary data embedded with sensor imagery (e.g. time, position, V/H). However, we have shown that recorders can already handle far more data than currently required, so the impact should be minimal.

3.0 SUMMARY OF RESULTS AND CONCLUSIONS

Figure 3.0-1 summarizes the UARV study conclusions. The figure highlights areas required for immediate technology development in order to meet basic interpreter requirements.

The UARV study results show:

- An imagery interpreter requires NIIRS 6-8 to fulfill currently stated tasking requirements for the Short Range UARV mission
- Current technology can support only NIIRS 3-5 within the Short Range UARV payload capacity.
- Areas recommended for technology development required to achieve a NIIRS 6-8 within Short Range UARV payload capacity are:
  - Increase sensor and associated/supporting equipment capabilities while maintaining and/or reducing payload weight
  - Interoperable data link tailored to necessary data rates
  - Smaller data recorder consistent with MIL-STD-2179-A
  - GPS accuracy in navigation/flight control system

Figure 3.0-1. Study Summary

Results show that NIIRS 3-5 sensors can perform area search missions and route reconnaissance missions required for the Short Range UARV, and still satisfy the imagery interpreter's resolution requirements. However, to meet stated tasking requirements for point targets, NIIRS 6-8 payloads are required to satisfy all of the essential elements of information (EEI's). The estimated weight of these high resolution payloads potentially exceeds the payload weight capacity envisioned for the Short Range UARV. *Therefore, the main emphasis of near term technology development* should focus on reducing system/payload weight while increasing equipment performance to achieve a NIIRS 6-8 capability. In addition to reducing component weights via miniaturization, we recommend developing an interoperable data link with the data rate necessary (28 Mb/s) for high resolution imaging; develop a more compact MIL-STD-2179 data recorder based on the 8 mm tape and tailored to the data rates and volumes of the UARV mission; and support development of a lightweight digital navigation/flight control system with Global Positioning System (GPS) accuracy.

Specific technology recommendations are summarized in Figure 3.0-2. Although all the technologies are important, those with the relatively highest risk are highlighted for more emphasis.

Technology Area	Recommendations
Sensors	• Initiate a weight reduction for existing EO-IR line scanner sensors and mini FLIRS /TV to benefit the low resolution class payload. • Initiate a cost and weight reduction program addressing the high resolution sensors (FLIRS/TV).
Data Link	• Continue development of the 10.71 Mbps, but focus on weight reduction. • Support production of a 28 Mbps version of the common data link to address the high resolution requirement.
Image Data Recorder	• Explore 8mm version(s) of the MIL-STD-2179 tape recorder to meet all requirements.
Navigation and Flight Controls	• Integrate the current research aimed at light-weight GPS guidance packages into the UAV interoperable architecture program.
Power	• Develop a generator capable of allowing up to 2 kw of extracted power to satisfy the high resolution power payload requirement.
Weight	• Initiate a weight reduction program focused at the high resolution payloads (sensors, data link, etc.).
Interoperability for Data Links	• Accelerate the common data link (CDL) program consistent within the NATO IDL study.
Interoperability for Image Data Recorders	• Examine the 8 mm version of the MIL-STD-2179 recorder for a 28 Mbps derivative to address the recorder requirement.
Interoperability for Flight Controls	• Develop a standard UARV command link and specification consistent with objectives for UAV interoperable architecture to benefit all UAV applications.
Interoperability for Image Format	• Pursue including the NATO STANAG 7023 imagery format in the UARV when appropriate.

Highest Risk Technology Areas

Figure 3.0-2 UARV Technology Recommendations

4.0 FURTHER RESEARCH

The UARV's role in the future battlefield will grow as technology progresses. Longer term research leading to these enhancements needs to be initiated in order to provide the needed technology and concepts.

4.1 Advanced Sensor Concepts

During the data and literature searches undertaken to develop the data base for this analysis, we noticed there is minimal effort addressing the next generation radar and laser radar or laser FLIR/radar systems having the unique characteristics required for UARV deployment. There are some conditions (battle smoke, haze phenomena, cloud cover, foliage, night, etc.), that degrade the performance of EO-IR technology sensors. (See RADC TR-87-145.) Foliage and camouflage penetration potential of some radar or laser based systems in addition to penetration in battle haze and adverse weather suggest technologies in this arena should be examined as upgrades to the UARV system. In the radar arena, there are two classes which would be applicable to the UARV, classical SARs and Holographic SARs; the first being a sidelooker, the latter a downlooker. The radar could be tailored to the desired features. For example, a relatively low frequency can be used to enhance foliage penetration, while a radar operating at short ranges can radiate at 60 GHz (a carbon dioxide absorption band) and remain quite undetectable. Laser radars are somewhat susceptible to battlefield obscurants but as active sources, can be used under many adverse conditions and provide both intensity and range information on the target area. This information can be automatically processed to enhance detection of targets under foliage or camouflage. Although research into all of these systems is continuing, the potential for a high payoff to the UARV reconnaissance community should be considered and a review conducted to determine which are applicable so that appropriate resources can be applied.

In addition to the sensors themselves, the technologies of image data compression are applicable and should be reviewed for applicability. Data compression has the potential of reducing both the data rates and volumes calculated in this report, since we used no data compression to determine the worst

case scenarios. The data compression techniques must be examined carefully, however, since improper compression can cause loss of resolution, dynamic range, or both. Since these changes would impact interpretability, an image chain analysis should be performed incorporating the effects of the compression to insure that the mission can be successfully completed.

4.2 Air Reconnaissance Tasking Guides

This study focused on the use of EO/IR imagery in order to extract tactical reconnaissance information. All mission areas were ultimately evaluated in terms of the object categories represented and the information elements which had to be answered for these missions according to the current air tasking guide. The current air target requesting and reporting guide explicitly includes only those elements of information that can be conveyed with photographic (visual wavelength) data. The incorporation of unique information elements that could be provided by an infrared or a radar image would make the guide more effective and allow for more complete target exploitation. For instance, an infrared image could provide information about how many aircraft are "on-line" at an airfield (detection of engine heat), or could provide information about enemy movement timelines (detection of heat left from vehicle tracks). It is recommended that the requesting and reporting guide be re-written to include the unique information that various wavelength sensors could provide. This would also provide a tool to weigh the merit of sensors based on factors other than resolution capabilities (photogrammetric standards).

APPENDIX A: TERMS OF REFERENCE

Sensor technology has made significant strides over the use of film-based cameras. Building on the basic concepts of television, numerous optical sensor concepts have been developed. Other concepts, such as SAR, were developed in parallel activities. These sensors use a variety of imaging implementations and cover most of the electromagnetic spectrum, predominantly, however, in the radio frequency (RF) to visible regions. Sensors can be grouped by the technique used to form the two dimensional image. Generally, all sensors that use the same image formation mechanism will exhibit the same geometric anomalies.

Sensors can have a single detector (or very limited numbers of detectors) and be scanned along both axes. Commonly, this is done with a polygonal mirror scanned in the cross track dimension. The forward motion of the platform provides the scan in the along track dimension. Figure A-1a shows this scenario. This type of sensor is known as a line scan system and is commonly used in downward-looking infrared (DLIR) systems such as the AN/AAD-5. The AN/AAD-5 uses 6-12 detectors scanned by a square mirror. The multiple detectors are used to limit the mirror scan rate (and therefore the data rate per channel). As the aircraft velocity to height ratio (V/H) increases, the perceived ground motion increases. Therefore, the sensor adds more detectors sequentially with increasing "V/H" so that the image doesn't have gaps between lines with the limited scan rate. The scan rate combined with twelve (12) active detectors is the basis for the maximum "V/H" value the sensor can accommodate.

The next class of sensors uses a linear array of many detectors. The array can be oriented to generate the scan along track (pushbroom sensors), or aligned nominally along track and mechanically scanned orthogonal to the array. The latter is often designed for shallow grazing angle oblique scenarios and the imagery is frequently displayed in a framing or raster format (like standard television). Figures A-1b and c pictorially represent these designs.

Sensors with two dimensional detector arrays are the next class. These are normally displayed as framing sensors at video rates (60 Hz). The output can be formatted to match RS-170 or RS-343 to be recorded and displayed as standard video. Most forward-looking infrared (FLIR) sensors are in this class. The number of detectors in the array determines the number of resolution elements in the output image

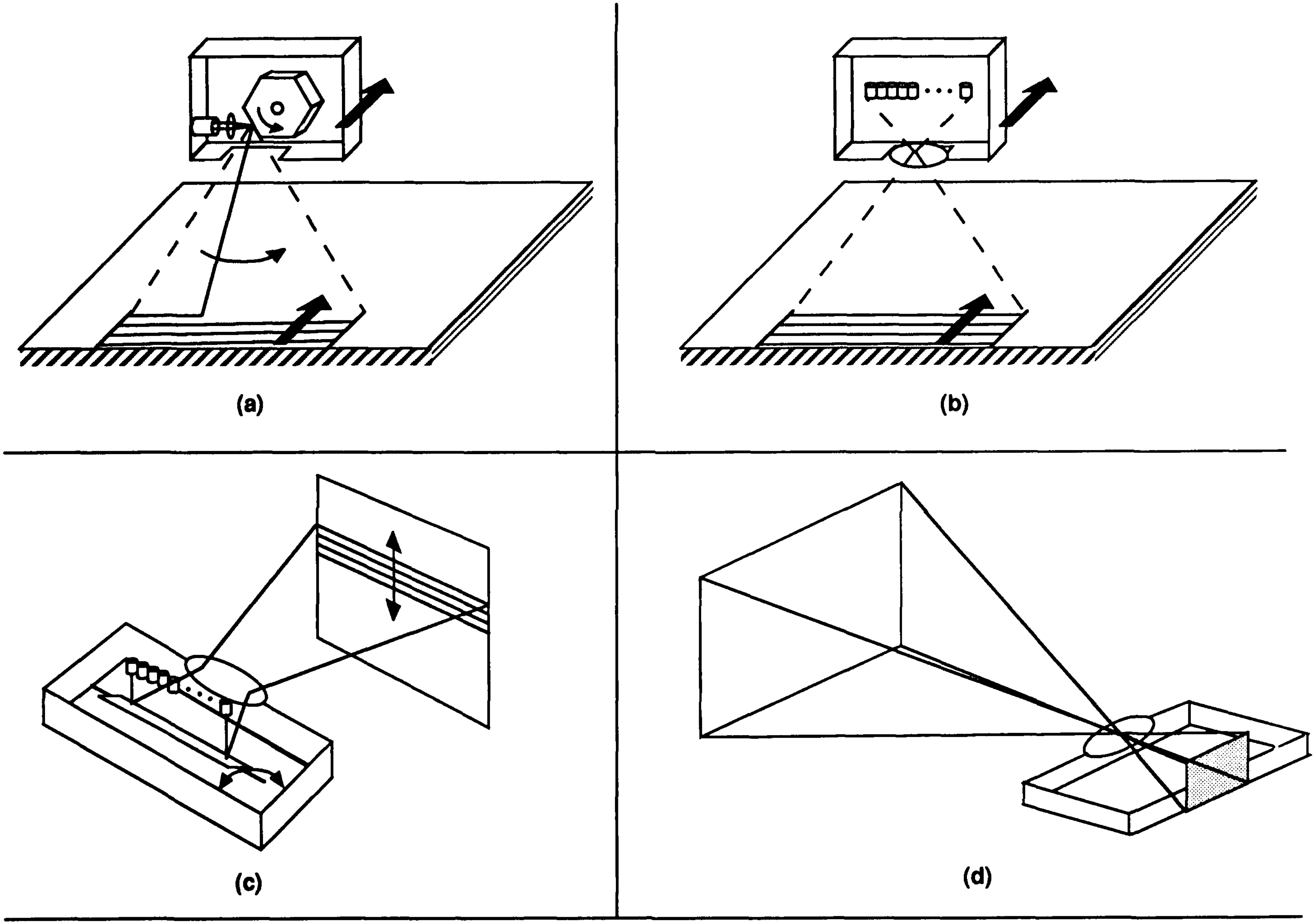


Figure A-1 Various Sensor Configurations

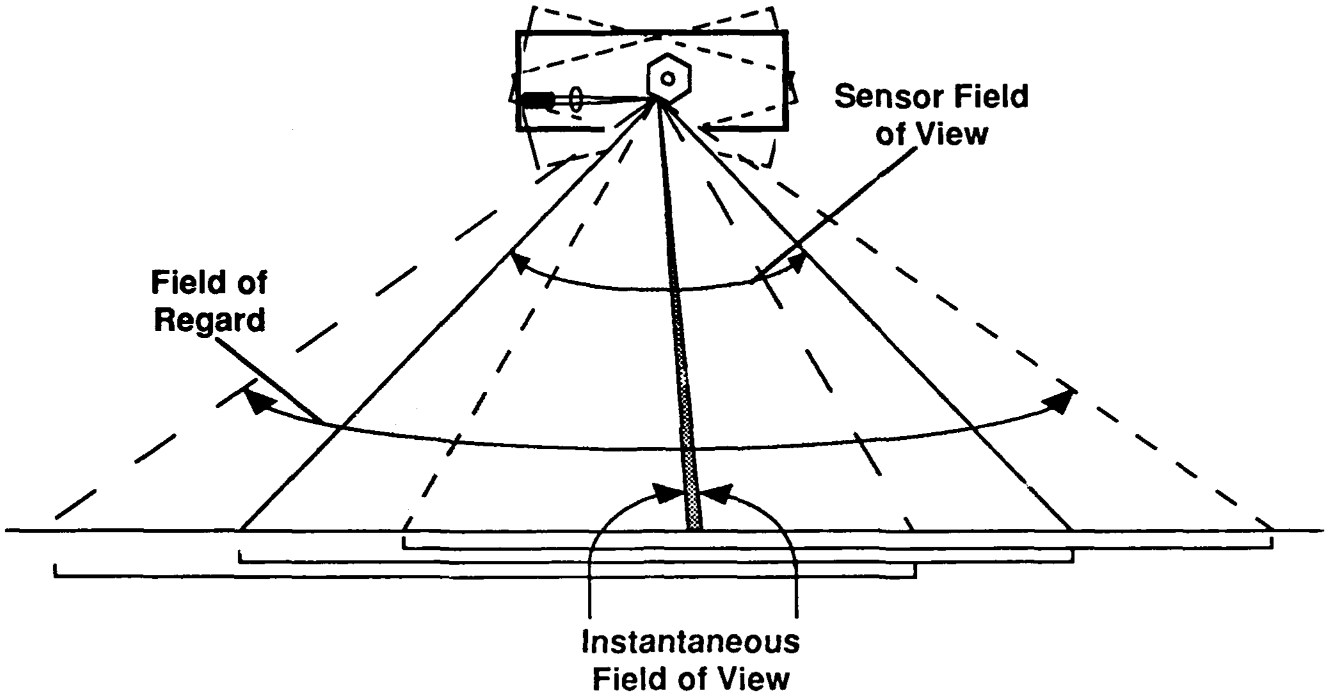
and the optics (magnification, zoom ratio) determine the sensor angular resolution. Figure A-1d represents a framing sensor.

The final class of sensors require data processing to form the imagery. Included in this group are a variety of radars; real aperture, synthetic aperture, holographic SAR, and laser radar. The first three are generally RF sensors operating in the L to Ka radio bands. Laser radars use visible or infrared lasers as the source. In the case of the real aperture, synthetic aperture, and laser radars, the range resolution is achieved by processing a frequency modulated carrier. Synthetic aperture radars also process the doppler variation in the along track dimension to generate a two dimensional, high resolution image. Laser radars scan two dimensionally and provide range to each pixel in addition to the intensity. Holographic SARs use the holographic principle to generate cross track resolution in an image immediately below the platform (classical SARs must image to the side to use the doppler variation.). These sensors require extensive processing and, with the current state-of-the-art, are outside the scope of capabilities of the Short Range UARV.

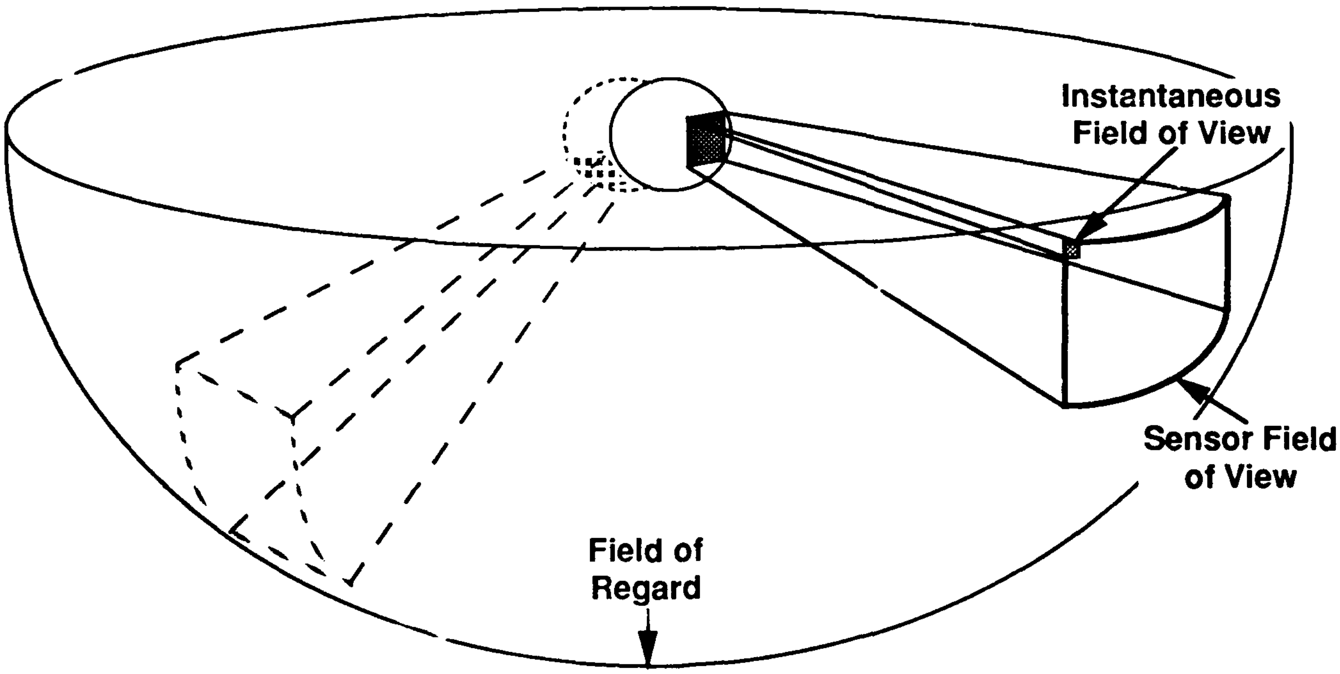
One other concept of importance is the relationship of field of view to resolution and sensor capabilities. For this discussion, the focus is limited to the first four (4) classes of sensors, since the processing of the last class heavily influences the definitions as applied them.

The term, "field of view" is generic and must be further defined. The first use is the "instantaneous field of view (IFOV)." This is the angle viewed by a single detector at one instant of time. The "sensor field of view (SFOV)" or "total field of view (TFOV)" is the total angle scanned by the detector . This is often the most frequent meaning of the term "field of view (FOV)", but since FOV can be used in other contexts, SFOV is preferred In sensors using platform motion to generate one axis of the image, these terms normally only apply to the cross track dimension. For framing sensors, they apply to both dimensions. Another term frequently used is the "field of regard." This is the angle through which a sensor can be pointed. Typically, this is done in downward looking sensors to accommodate platform roll and pitch, and in framing sensors to point to the object of interest. These angles are shown on Figure A-2.

Instantaneous Field of View is directly related to the resolution of the sensor. It represents the smallest spot that can be individually detected, is measured in angular dimensions (milliradians), and can be used with the slant range to the target to calculate the linear resolution using simple geometry. The Sensor Field of View is related to the IFOV by the number of samples in a line or scan. For the AN/AAD-5 IR line scanner, the IFOV was approximately .5 mrad and the scan line consisted of just over 4000 pixels.



(A) Line Scan Sensor (DLIR)



(B) Framing Sensor (FLIR)

Figure A-2 Fields of View and Regard

This gave a sensor field of view of approximately 120 degrees. The field of regard was about 150 degrees, thereby allowing about +15 degrees of roll correction to keep the sensor pointing vertically. For the AN/AVQ-26 FLIR, the IFOV was approximately .5 mrad in both dimensions. It had the standard 4 to 3 aspect of television and an 875 line video output, giving just over 22 degrees of vertical field of view and about 30 degrees of horizontal field of view. The sensor head can rotate through 360 degrees of azimuth and 180 degrees of elevation, so the field of regard in this case is the entire lower hemisphere below the platform.

In addition to GRD, one must also define reasonable limits for the third dimension of an image representation, the number of gray scale tones representing an image. This characteristic is orthogonal to the resolution of the image. As with resolution, it affects the image quality significantly, but in a different manner. The number of gray scale tones sets the maximum data word length necessary to define each resolution cell (pixel). For example, an 8-bit data word corresponds to 2^8 or 256 quantization levels. Higher quantization rates allow, within the limits of the eye, more detail to be perceived within similarly shaded areas of the image.

Both resolution and quantization level affect the total data quantity and rates. In developing imaging systems, the design must be balanced so as not to drive the data rates high with one characteristic, while the second becomes the limit on image quality. Figure A-3 highlights the effects of changing resolution and dynamic range on an image. In the vertical axis, the image suffers decreasing resolution. The sample pixel size is shown on the left side next to the magnification ratio. The horizontal axis decreases the dynamic range from four bits per pixel to one. In the one bit per pixel images, every pixel must be either white or black. Thus the upper left image is full resolution and four bits per pixel, while the lower right is sixteen times worse resolution and only one bit per pixel. It is clear that moving in either direction causes the information in the original image to be rapidly lost.

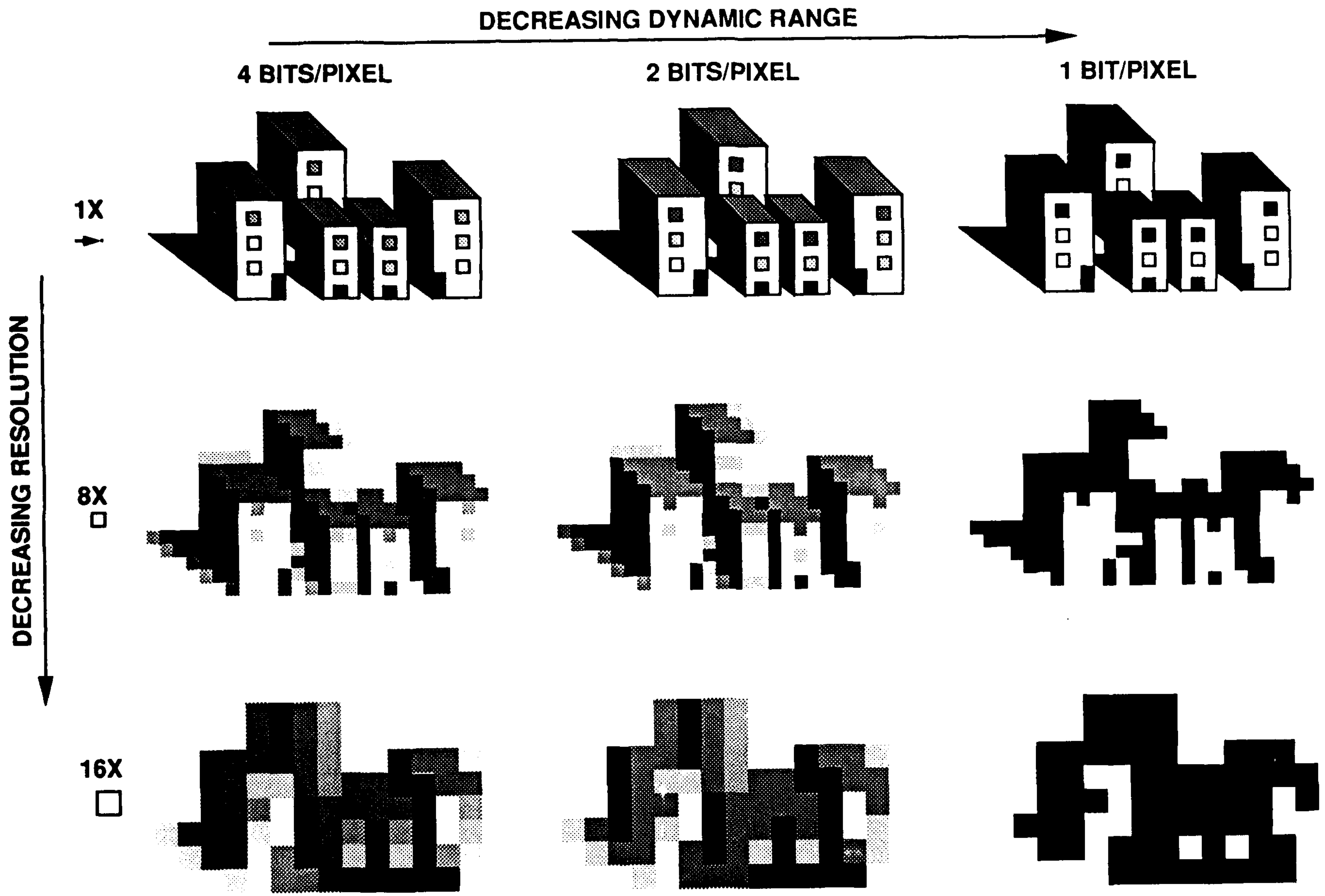


Figure A-3
Effects of Resolution and Dynamic Range On Imagery

APPENDIX B: ACRONYM LIST

AFM	Air Force Manual
AGL	Above Ground Level
ATARS	Advanced Tactical Air Reconnaissance System
BMA	Boeing Military Aircraft Corporation
bps	bits per second
C^2	Command and Control
C^3I	Command, Control, Communications, and Intelligence
CDL	Common Data Link
CP	Command Post
DARPA	Defense Advanced Research Projects Agency
DLIR	*Downward Looking Infrared*
DoD	Department of Defense
EEI	Essential Elements of Information
EIA	Electronics Industry Associates (reference standards)
EO	Electro-optical
EOCAM	Electro-optical Cameras (normally visible light sensitive)
EW	Electronic Warfare
FLIR	Forward Looking Infrared
FLOT	Forward Line of Troops
FOG	Fiber Optic Gyro
FOV	Field of View (generic term)
GGP	GPS Guidance Package
GPS	Global Positioning System
GRD	Ground Resolved Distance
GTOW	Gross Take-Off Weight
ID	Identification
IFOV	Instantaneous Field of View (angular measure)
II	Imagery Interpreter

IMU	Inertial Measurement Unit
INS	Inertial Navigation System
IR	Infrared
ISO OSI	International Standards Organization Open Systems Interconnect
JPO	Joint Program Office
JSIPS	Joint Service Imagery Processing System
KSC	Knowledge Systems Concepts, Inc
MASINT	Measurement and Signatures Intelligence
Mbps	Megabits per second
MET	Meteorology
mm	millimeters
mrad	milliradians
NATO	North Atlantic Treaty Organization
NBC	Nuclear, Biological, and Chemical (Reconnaissance)
NIIDLS	NATO Interoperable Imagery Data Link Study
NIIRS	National Imagery Interpretability Rating Scale
PMD	Program Management Direction
PME	Prime Mission Equipment
R & D	Research and Development
RF	Radio Frequency
RL	Rome Laboratory, US Air Force (previously Rome Air Development Center, RADC)
RL/IRR	Image Systems Division, Rome Lab
RL/IRRE	Image Exploitation Branch, Rome Lab
SAR	Synthetic Aperture Radar
SFOV	Sensor Field of View (angular measure)
SIGINT	Signals Intelligence
SMPTE	Society of Motion Picture and Television Engineers (reference D-1 standard)
STANAG	Standardization Agreement
TFOV	Total Field of View (angular measure)
UARV	Unmanned Aerial Reconnaissance Vehicle
UARVII	Unmanned Aerial Reconnaissance Vehicle Imagery Interpretation Study
UAV	Unmanned Aerial Vehicle
UAV-SR	Unmanned Aerial Vehicle, Short Range
V/H	Velocity to Height Ratio

NOTE: Although this report references *limited documents, no limited information has been extracted.

APPENDIX C: REFERENCES

This section provides a description of documents and other references used to complete the study.

*RADC-TR-87-145, "F-16 Reconnaissance Ground Exploitation Concept Validation", Capt John W. Buffington and Ronald B. Haynes, Rome Air Development Center, Griffiss AFB NY, August 1987 - B117296L - DOD & DOD contractors only; premature dissem., Aug 87

*RADC-TR-90-370, "Imagery Interpretation Requirements for Reconnaissance Systems", MSgt Charles Walling, Rome Laboratory, Griffiss AFB NY, December 1990 - B151397-USGO agencies & their contractors; administration/operational use, Dec 90.

"Unmanned Aerial Vehicle Master Plan", Department of Defense, June 1989

"Unmanned Aerial Vehicle Master Plan", Department of Defense, February 1990 update

"Short Range UAV Mission Description and Flight Profiles", Lavi Technical Services, Inc., March 1989

"Unmanned Aerial Vehicle Short Range (UAV-SR) Joint Program System Specifications", Department of Defense, July 1989

NATO Standardization Agreement (STANAG) 3596 (IRI) Annex B - "Air Reconnaissance Requesting and Target Reporting Guide", April 1980.

NATO Standardization Agreement (STANAG) 3769 (IRI) Annex C - "Minimum Resolved Object Sizes for Imagery Interpretation", March 1980.

NATO Standardization Agreement (STANAG) 7023 "Air Reconnaissance Imagery Data Architecture", approval pending

NATO Standardization Agreement (STANAG) 7024 "Air Reconnaissance Cassette Tape Recorder Standard", approval pending

AFM 200-50 Volume I and II, "Image Interpretation Handbook", U.S. DoD Joint Service Publication, December 1967.

"Soft Copy Display of Electro-Optical Imagery", Dr. S. J. Briggs, SPIE proceedings Volume 762, 1987

"Gray Scale Requirements for Complex Images", Murch and Weimar, Society for Information Display Digest of Technical Papers, Volume XXI, May 1990

MIL-STD-2179, "Helical Digital Recording Format for 19mm Magnetic Tape Cassette Recorders/Reproducers", January 1987, Revision to incorporate 8mm tape format is pending.

MIL-STD-1553, "Aircraft Internal Time Division Command/Response Multiplex Data Bus", September 1978

SMPTE D-1, "Electronic Imagery Tape Recorder/Cassette Standard"

EIA RS-170, "Electrical Performance Standards; Monochrome Television Studio Facilities"

EIA RS-343, "Electrical Performance Standards for High Resolution Monochrome Closed Circuit Television Camera"

APPENDIX D: POINTS of CONTACT

This study received an overwhelming level of support from both government offices and the equipment and sensor manufacturers. We especially appreciate the technical frankness and willingness to share product information and data for this study.

Government

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Industry

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Knowledge Systems Concepts, Inc	Max Rodgers	(315) 336-0500

Real Time Ground Interpretation Systems

E-Systems (JSIPS)	J. R. Collins, J. Milford and M. Spooner
Goodyear - Loral	Dr. N. Abbott, F. Kelley

FLIR Systems

The Boeing B-1B Data Base previously assembled for the Situation Awareness and Targeting FLIRS was available for this effort. This data base includes pertinent FLIR information from:

Honeywell-Loral
GEC of England
Kollmorgan
Barr and Stroud LTD of England
Ford Aerospace-Loral
Hughes
Texas Instruments
Kollsman
FLIR Systems Inc.
Raphael of Israel
Westinghouse Electro-Optical Group

Proprietary restrictions requested on some supplier's data was respected.

UAV/RPV Systems

Teledyne Ryan	N. Sakamoto, B. Hansen
E-Systems	J. Lilly
Boeing of Canada	M. Sloan

Leading Systems Inc.	B. Clark
Development Sciences Corporation	Dr. G. Harris - Consultant

Navigation Systems Upgrades

Trimble Electronics	C. Armature, I. Tannemacker
Collins-Rockwell	J. Donaldson
Plessy Corporation	J. Geyer, M. McDonnell
Teledyne Electronics	W. Roof, M. Jamerson, R. Felix
II Morrow Electronics	
Bendix/King Corporation	
Litton Guidance and Controls System	L. Lynch
Honeywell Corporation	J. Crobuck

Reconnaissance Data Links

Sperry-Unisys	H. Peckham
Conic-Loral	S. Borowski
Goodyear-Loral	G. Boldra
Harris Corporation	S. Fox
E. Systems	G. Seymour

Small Tape Recorder

Data Tape Inc.	D. Frassens
TEAC Corporation	C. Reardon, J. Hemphill
NEC US	A. Weigandt (Consultant), T. Angustine
Measurement Technology Inc.	T. Dean
Honeywell Corporation	A. Fulton

Electro-Optical Reconnaissance Sensors

Fairchild-Loral	D. Pickard, B. Mathews
TRICOR Systems Inc.	P. Allen
CAI Division Recon/Optical Inc.	E. Kaszubouski

Infrared Line Scanner Systems

Honeywell-Loral	P. Buckley
Texas Instruments	D. Stageberg
British Aerospace	S. McCallam

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